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At Sea Personnel Transfer Concepts

by

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14. ABSTRACT
At sea personnel transfer on any level is an operation that poses a problem for the modern Navy. Current operations are high risk, slow, inefficient, costly, and can only be accomplished in low sea states. As a result of this apparent gap in capability, ONR has deemed it necessary to form concepts which can evolve with the Navy's ever changing vision of Sea Basing. ONR and NAVSEA have created a group within CISD to spur such developments. The specific goal of this group is to develop a conceptual solution to the problem of delivering high throughput transfer of assault personnel and associated assault logistics between two vessels underway in a seaway. After preliminary research three main concepts have been chosen for further development. The three concepts consist of a gondola idea which utilizes mooring lines and ski lift technologies, a rope bridge designed to be flexible and storable, and a spar ship on which hydraulic ramp/ladders are stationed. Each of these ideas possesses potential to be a reasonable solution to the problem of at sea personnel transfer in high sea states. Development of each system will provide better insight to the capabilities of each system and how they might meet the requirements of the Navy.

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Abstract

At sea personnel transfer on any level is an operation that poses a problem for the modern Navy. Current operations are high risk, slow, inefficient, costly, and can only be accomplished in low sea states. As a result of this apparent gap in capability, ONR has deemed it necessary to form concepts which can evolve with the Navy's ever changing vision of Sea Basing. ONR and NAVSEA have created a group within CISD to spur such developments. The specific goal of this group is to develop a conceptual solution to the problem of delivering high throughput transfer of assault personnel and associated assault logistics between two vessels underway in a seaway. After preliminary research three main concepts have been chosen for further development. The three concepts consist of a gondola idea which utilizes mooring lines and ski lift technologies, a rope bridge designed to be flexible and storable, and a spar ship on which hydraulic ramp/ladders are stationed. Each of these ideas possesses potential to be a reasonable solution to the problem of at sea personnel transfer in high sea states. Development of each system will provide better insight to the capabilities of each system and how they might meet the requirements of the Navy.

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1. Section I - Introduction

1.1. Mission Statement

The mission of the "At Sea Personnel Transfer Concepts" Innovation Cell was to bring a fresh perspective to the problem of delivering high throughput transfer of assault personnel and associated assault logistics between two vessels in a seaway. Along with the development of Sea Power 21 there is a renewed interest in transferring personnel efficiently while at sea. ONR and NAVSEA have created a group within CISD to produce new concepts for personnel transfer that could better match the vision of sea basing. The team approached the topic with little knowledge of current systems with the intention of designing something uninfluenced by convention. The primary objective was to design something that will safely transfer combat ready marines as quickly as possible from one vessel to another while operating in high sea states. The transferring system is expected to operate on vessels similar to an LMSR, MLP, or JHSV. However, the operation with any vessel from LCAC size upwards shall not be precluded.

1.2. Background

The United Sates Navy and Marine Corps have an ever changing outlook for future war tactics. While enemies continue to change their battle tactics, the United States military sees the need to change their strategy in maintaining the demands of today's evolution in fighting war. As a way to combat new threats to national security, the Navy has developed a plan to continue evolving its strategy well into the 21st century with a concept known as Sea Power 21. Sea Power 21 is the Navy's vision of organizing and executing future operations under three main categories: Sea Shield, Sea Basing, and Sea Strike (Clark).

Figure 1.2.1: Sea Power 21 (Clark)

The Sea Shield will provide defense for military forces ashore and in the sea from outside enemy forces. It will accomplish these goals through an overwhelming controllable presence in the world's seaways. This overwhelming presence will deter enemies and ensure the safety of our allies, troops and homeland by defeating all enemy weapons (Clark).

The Sea Strike group will be the offensive group carrying out desired objectives ashore with assistance from an assortment of naval capabilities. These capabilities include, "long-range, precise aircraft and missile fires; large-volume covert strike capability; high-tempo decisive maneuver; Naval Surface Fire Support (NSFS); maritime special operations; and information operations to capitalize on the strategic agility, operational maneuverability, precise weapons employment, battlespace influence capabilities and persistent sustainment of naval forces (Naval Transportation Roadmap 2003: Assured Access & Power Projection … From The Sea)."

The Sea Basing group will act as the central focal point where cargo and troops are stored for an extended period of time until needed. This base will incorporate the "complementary characteristics of amphibious, maritime prepositioning, and critical connecting platforms (Naval Transportation Roadmap 2003: Assured Access & Power Projection … From The Sea)."

As seen in the figure 1.2.1, these capabilities will be connected together by ForceNet, an integrated information technology network that will consist of advanced sensors, weapons, and support systems integrated with maritime command (Clark).

In the process of developing Sea Shield, Sea Strike, and Sea Basing, there are three organizational steps: Sea Trial, Sea Warrior, and Sea Enterprise, that must be taken before any part of Sea Power 21 is fully operational. The Sea Trial division implements a continuous process of rapid conceptual and technological development as a means to advance protection and strategy against any enemy. In the Sea Warrior division, the Navy wants to streamline many of its operations by reducing the number of Sailors and training them in such a way to optimize their use in selective missions. Finally the Sea Enterprise division wishes to update the existing fleet with the latest in technology in order to be compatible with current and future naval systems. No organizational step has priority over the other; rather they are all being implemented concurrently and are essential to the development of Sea Power 21. This vision for the future will replace the current method of conducting military operations abroad.

Currently the Navy and Marine Corps must establish a base of operations ashore near where the military operations are conducted. Unfortunately, this method is very vulnerable to enemy attack crippling the desired objective and is a costly "middleman" between sea and land operations. Also this method relies heavily on the use of foreign ports which may require permission for use or must be acquired forcefully. Under the concept of Sea Basing, the Navy and the Marine Corps would conduct operations directly from a base at sea eliminating the "middleman" while providing a safe haven for supplies and soldiers from enemy attack (O'Rourke, 13). The Sea Base itself is not a single vessel but rather a collection of vessels deployed for a period of time then reconstituted after the mission to be redeployed for future conflicts. The Navy envisions using a 14-ship MPF(F) squadron to be placed in different seaways throughout the world. These vessels would act like a Sea Base supporting and allowing

the MEB force to be established quickly and securely offshore. Of those 14 ships, 12 will have to be built and two are from the existing MPF fleet. The 12-ships that are needed include: 3 modified LMSRs, 2 LHA(R)s, 1 LHD, 3 modified TAKE-1s, and 3 MLPs (O'Rourke, 16). Having a wide variety of ships and no port raises the issue of transferring cargo and personnel from ship to ship safely and efficiently in unpredictable seas.

The focus of this project corresponds to the intra-theater workings of the Sea Basing concept specifically related to personnel transport. Currently there are few efficient and effective ways of transferring large numbers of personnel from vessel to vessel in high sea states. As this idea of "Sea Power 21" becomes more of a reality, transferring high volumes of personnel in an intra-theater setting becomes a larger issue. Currently the preferred method of personnel transport at sea is through the use of helicopters and other types of marine vehicles. As stated in section 1.1 of this report, it is the mission of this project is to find better alternatives in transferring high volumes personnel from vessel to vessel safely and effectively while working in the high seas.

1.3. Current Methods:

The preferred method of transferring personnel from vessel to vessel is through the use of helicopters. When large numbers of personnel are transferred, the process becomes very costly due to fuel consumption and the time required for helicopter repair. As sea state increases so does the risk and cost when using helicopters. However, this method of at sea personnel transfer is not the only option.

Another method the Navy currently uses to transfer personnel from one vessel to another utilizes a wire transfer system of highlines, inhaul lines, and outhaul lines, much like cargo and fuel transfer at sea. Personnel can be transferred with relatively short notice using a 4" double braided, polyester synthetic highline instead of steel cable. The current transfer chair seen in figure 1.3.1 is aluminum and equipped with reserve floatation material. The chair attaches to the highline which has a movable block used to suspend and move the chair along the highline. This apparatus is used for ferrying one or two individuals at a time. The velocity at which the chair moves is controlled manually through the use of sailors pulling on lines strung between the two vessels.

Figure 1.3.1: Transfer chair

According to USS Kitty Hawk Sailors involved in the personnel highline transfer exercise on April 20, 2002, seen in figure1.3.1, this process is ordinarily reserved for smaller vessels (Cunningham).

A third method utilizes a well deck. Landing craft would land or dock near a well deck of a larger vessel while personnel board the craft. This process has a low throughput rate and becomes dangerous in anything but calm seas. Therefore it is the mission of this team to create a more effective and safer way of transferring personnel at sea.

1.4. Requirements

Through the use of the mission statement, design concept requirements were created and developed. The requirements in order of importance are as follows:

1	Safety
2	Transfer rate
3	Functionality at Sea State 4
4	Simplicity
5	Low maintenance
6	Rapid and automated
7	Easily retro-fitted
8	Ability to transfer personnel with equipment
9	Protection from environment
10	Light weight/ small size
11	Easily stowed
12	Low power consumption
13	Ease in training
14	Low cost
15	Functionality at Sea State 6

Table 1.4.1: Requirements

1.5. Design Process

The design process used for the development of concept systems was taken from a generic design cycle and adjusted to fit this particular task. The process was broken down into 4 main categories: brainstorming, requirements, decision making and further development. Each of these stages is a mini-process in and of itself. The team was given a total of 10 weeks to complete the design process and produce at least one concept which could be considered worthy of further research and development.

1.5.1. Brainstorm

To start off the design cycle, a brainstorming session was conducted amongst the team members. This session was designed to produce as many ideas as possible with out the

constraints of taking into account specific criteria. By producing as many ideas as possible, no matter the practicality, the likely hood of developing a respectable idea increased. Also, a large list of ideas allowed for the possibility of combining ideas to produce a more capable end product.

The ideas which surfaced from the brainstorming were broken up into broader categories for easier evaluation. These categories were: separate vessels, guided systems, lift systems, and fixed systems. The separate vessels category encompasses intermediate vessels which would house a system that could be used for transfers. Development of both the system and the vessel itself need to take place. Guided systems are systems which use a flexible track/path, such as cables, to direct and support the process. Lifting systems are those that utilize cranes and other vertically moving devices, such as elevators. Fixed systems are similar to guided systems. However, fixed systems are different because, unlike guided systems, they are rigid.

Once the main brainstorming was done, truly eccentric ideas were set aside and no longer considered. The remaining ideas were listed under the corresponding categories and sub-categories and then brief descriptions were written about each.

Separate Vessels:

1. Ships:

- Joint High Speed Vessels (JHSV): These ships are not currently in use; rather they are still in the developmental stage. The particular plans that were looked at were for a ship which would have a beam of 100 feet, a length of 370 feet and a draft of 12-14 feet. The JHSV are an attractive option because of the ample amount of deck space available as well as their excellent sea keeping abilities.

- Landing Craft Air Cushion (LCAC):The LCAC would be a great assist to the project, because unlike the JHSV, there are already LCACs made and in use currently. However, the problem with using LCACs is that they are practically on the waterline, creating a great distance in height between vessels.

- Small Water plane Area Twin Hull (SWATH): These types of ships are desirable because they have great sea keeping abilities, which is a good quality to have in rough seas. There are SWATHs already in use for purposes of personnel transfer for oil rigs at sea.

2. Planes:

Sea planes: Sea planes were looked at because originally it was thought that the transfer process might go from the sea base to a ship with similar characteristics as that of an aircraft carrier. If a seaplane could be launched from a sea base with about 20-30 men (not including the crew) and safely land on the deck or in the water to be scooped up in some way, it would be a fairly good way to transfer men.

3. Helicopter:

The idea of using helicopters was briefly talked about simply because it is a way the navy is currently using to transfer men. The transfer rate is relatively slow, the cost is tremendous and the maintenance on helicopters requires many man hours. Also, landing a helicopter on a ship in sea state 4 is not up to the safety level that is wanted.

4. Inflatable Crafts**:**

- Blimps: A blimp system would be a crate in which the entire system is stored. This crate would be a 20 foot specially made storage container (probably made out of aluminum) which could be easily stored in the cargo hold of the ship. It would also become the gondola for the blimp. Lines would connect each of the two ships. These lines would then act as a guidance system for the blimp. The balloon part of the blimp would then be inflated using a compressor. This balloon would remain attached to the gondola which was once the storage container. Men would then enter the gondola and then an engine or motor would propel the blimp across the gap between the two ships. With the lines guiding the craft, it would then land on the other ship.

- Airship: The airship is almost an identical idea with the exception that the balloon on an airship contains an internal structure where as the blimp does not.

5. Spar ships**:**

Spar ships are a concept the navy is currently working on. To use this for the idea of personnel transfer, the ship would be drastically scaled down. This system would, for all practical purposes, be a high tech platform that could be raised and lowered to accommodate for the change in height between ships of different sizes. This platform would need an advanced dynamic positioning system to allow for use in high sea states. A current idea is to use fire truck ladders that would work on a hydraulic system. These ladders could be pivoted from a position facing straight forward to a position pointing off either side of the ship. A universal joint of sorts would allow for the compensation of large changes in motion for any of the ships involved.

6. Submarines**:**

The idea of using submarines evolved from watching movies in which there is always an "escape pod" aboard every ship. These small submarines/escape pods would be release from the ship which is sending troops. This sub would be maneuvered over to the receive ship where it would either be scooped up or taken into a designated part of the ship underwater. The benefits to doing any transfers under water are that it eliminated a good amount of the forces caused by surface waves as well as taking wind and rain completely out of the equation.

Guided Systems:

1. Zip Lines

There are three different approaches to the zip line idea. The first of which is merely a cable draped from a high ship to a low ship which men would slide across with the help of a roller device. Another approach is that zip line roller device would be in some way motorized. This would allow for transfers to occur from a low ship to a high ship. The third idea is having the cable which is connects the two ships rotate between the ships and having a zip line or harness be permanently attached to the cable.

2. Ski Lift

The ski lift system would require a similar set up to that of the zip line. There would be a set of cables which would connect the two desired ships. These cables would be motorized so that they would make a loop from one ship to the other and then back. Connected to these wire would be a chair similar to a ski lift. This would allow men to sit down on the chair as it comes around, be taken across the gap, and then dismount on to the deck of the receiving ship.

3. Cable Cars/ Aerial Lift Gondolas

Cable cars and aerial lift gondolas are basically the same idea with a few minor differences. These systems would work similarly to the zip line in the fact that it is a system that functions with the use of cables. These cables would be strung from ship to ship but instead of using a zip line or harness, the system would use a lightweight metal or composite frame to act as a gondola. Like the zip line, there are two different ways to propel the unit. The first of which is to make the gondola itself motorized. It would have cables running along both the top and bottom of the gondola for stability purposes. This would also allow for a motor to be places at both points, so neither motor would require that much over all horsepower. The second method it to have the cables motorized can the gondola directly attached to the cables. The motor for this system would be placed on the delivery vessel so that the receiving vessel would require little by way of retro fitting.

Cranes/ Lifting systems:

1. Elevator**:**

An elevator-like system would consist of a vertically rotating series of platforms. The structure would act similar to that of a Ferris wheel because the platforms would remain strictly horizontal while the wheel on the inside rotates in a circular motion. As the wheel rotates, the men would board the platform from some sort of smaller vessel than be brought up to the level of a deck or available loading zone so they can head off the platform. The elevator/ Ferris wheel would be oriented so that the wheel is rotating parallel to the larger ship.

2. Lift Cars

The lift car concept would require the use of a crane aboard one of the two ships or vessels being used for the transfers. At the moment it is assumed that this crane would be supplied on a ship such as a spar platform. By making this assumption, having to retro-fit a previously existing ship with a crane can be cut out of the design process. To the end of this crane, a special light weight car would be attached. This car was originally planned to hold about 8 men, but after taking in to consideration the weight and size of the gear soldiers carry, the number was assumed to be closer to 5 or 6. The idea of having a dynamic positioning system (DP) associated with the crane as well as the ship itself was considered. This would allow for the car to be safely set on to the deck of the receiving ship.

3. Hydraulic Platforms

This would be, in its most basic form, a platform attached to a hydraulic pump that would allow for the lowering and raising of it. The benefit of this system is it would allow for the transfer of people on to different heights of ships.

Fixed Systems:

1. Ramps, Bridges and Tunnels:

- Airline Tunnel: This tunnel would mimic the tunnels used to go from the gate at an airport to the airplane itself. These would be a sort of telescoping bridge/tunnel that would be covered on all four sides to protect against the elements. The materials need to be flexible enough to deal with this twisting yet strong enough to support troops. It would need to have a shock system on both ends to account for changes in vertical position with out jarring the men.

- Underwater Tunnel: An underwater tunnel/worm hole would go from either the underside of a parent ship to the underside of a receiving ship or from side to side. In both set up the main portion of the tunnel will be located under the water. This will eliminate a lot of the disturbance caused by the high waves and strong winds.

- Rope Bridge: A rope bridge or other type of very flexible bridge would be used to connect the two ships and allow for the men to walk across. The walls and the ceiling would be made out of a canvas material to protect from the elements. The material for the floor, ceiling and walls would all be rolled out and supported by thick main cables that would be strung from ship to ship. On one side (the delivery side) the cables would be wound on cable reels which would be connected to a motor. On the over side (the receiving side) the cables would be threaded through a pulley system which would be connected to a steel (or other strong material) frame the same shape as the bridge. The shape that is currently being developed is a trapezoid with the

smaller edge on the floor and the larger edge on the ceiling (to accommodate soldier's shoulders and packs).

2. Belts

A conveyer belt system for transportation would require a rigid bridge like structure to be placed between two ships with a rubber track placed around it. It would need to have the powering capabilities to be able to loop around the bridge while carrying men with their packs. This brought up a lot of torsion issues and well as mechanical problems.

3. Tracks

The track idea is similar to that of the gondola or cable car idea as seen previously. The major difference between the two ideas is that this particular system would be based around a ridged (or slightly flexible) track structure as opposed to the very flexible cables. This would allow for the path of the car to be very predictable and reduce the amount the car would sway.

1.5.2. Requirement Development

The second step in the design cycle was to create a list of requirements that a system would have to fulfill to be considered as a concept worth developing. These requirements were broken down into two main categories: mandatory and derived. Mandatory requirements are those which were given in the initial briefing which, if not met, would justify an idea being rejected without further consideration. These requirements, in order of importance, are as follows:

- Safety of troops

Safety for the soldiers which will be using the system was deemed the top priority. The system needs to be able to get soldiers and troops from the Sea Base (or other designated location) to the receiving ship with little to no time being exposed to potentially dangerous situations during the deployment, usage and retrieval phases.

The failure of the system needs to be taken into consideration. If a particular mechanism were to fail, the system must be designed to assure the safety of both the troops which are being transferred as well as those who are operating the system.

The level of safety for the system needs to account for minor amount of improper usage. This would encompass human errors during operation such as tripping or losing grip of an item. The system needs to consider such incidents and function safely regardless.

- Must be functional in sea state 4

The functionality of the system at sea state 4 is a requirement for this system because transfer methods at sea states 3 and lower are already in practice. The Navy wants a system that will be able to handle higher sea states so that calm seas will not be necessary for transfers to take place. This will greatly increase both the time frame and the locations at which military operations can be conducted.

If a system can potentially handle the forces created by the 6 foot waves and 18 knot winds that sea state 4 is defined by, it can be considered as an idea which validates further investigation.

- Must have a high transfer rate

The intention of this task is not to create a system which will allow for the transfer of a handful of crew. Rather, due to the involvement with Sea Basing, the system's purpose is to transfer large numbers of troops at a high rate from a Sea Base (or other designated location) to a receiving ship. A system that carries 4 to 5 people across at a time is not practical when there are 1,000 men that need to be transferred.

If the system involves men walking, the time it takes for an average soldier to walk as well as number of soldiers that can be walking at once needs to be accounted for. If the system involves loading and unloading, those times need to be evaluated. Also, the variance in time due to the difference in length between vessels needs to be calculated and analyzed.

The transfer rate, however, cannot compromise the safety of the troops both operating and using the system.

- Needs to be easily retro-fitted to previously existing ships

Although the ability to retro-fit a ship may be an obvious requirement, the ease at which this is done is important. The transition between old systems and the new system needs to be as low cost and require as little labor as possible. To do this, the devices and mechanisms which are already onboard military vessels need to be considered for use in new systems. Also, deck space maybe limited in some cases, so encroachment on important spaces, such as flight decks, must be avoided.

- Needs to have rapid, automated engagement and release mechanisms

A system which uses almost no man power for the engagement and release of the system is highly desirable. The use of men to operate machinery introduces a greater deal of risk into a process than if it were to be fully automated. Although automated systems tend to be more complex and require more maintenance, the elimination of human error increases the safety of the over all system.

The system should be able to be engaged in a rapid fashion, setting aside the majority of the time allowed for the actual transferring of men. The faster a system

can be deployed, the greater the number of soldiers that can be transferred. This requirement ties in directly with the high transfer rate.

- Must be low in cost

 Although this is not the most important requirement for the team, it is one that needs to be considered. The cost of implementing a new system can potentially be great if the system involves manufacturing equipment, retro-fitting all vessels or even running off a large amount of power. Each of these areas needs to be evaluated because, even though a system may fill all other requirements, if the price tag is outlandish, the system is likely to be discarded. This requirement will tie in with all other requirements, acting like a check and balance system. Take high transfer rates for example; the fastest means of transferring personnel may be passed up if a similar systems that is slightly slower but over all less expensive is presented. This is true for all criteria; it is merely a matter of finding the desired balance between what is wanted and how much is willing to be spent.

Unlike mandatory requirements, derived requirements were decided upon by the team. These are requirements that are not essential; however, the fulfillment of these will allow the system to be the most efficient system possible. The derived requirements, in no particular order, are as follows:

- Should allow for transport of troops with packs

 The transfer of troops with their packs would allow the system to be more efficient because it would eliminate the need to have a separate unit for shipping packs and supplies.

- Should provide protection from environment

 High sea states bring high waves and high winds, which pose a problem for troops trying to transfer from vessel to vessel. The spray caused by large waves can soak a soldier if there is no barrier in place. Getting wet can not only affect the health of a soldier but also his safety. If troops get wet, they are more likely to slip, or lose their grip of equipment while in the transfer process.

- Must be easily stored

 Since storage on the deck of most naval ships is not readily available, the system needs to have the ability to be broken down and stored. It is preferable to have the system, when in the disassembled state, that can fit into a standard TEU container.

- Needs to be of reasonable weight and size

 This requirement is directly related to being easily stored. If the system is too large in either size or weight and is not able to be stored in a TEU container, then the

system may become more of a hindrance than useful system. Also, the weight needs to not be so large as to affect the hydrostatic properties of the vessel, such as centers of buoyancy and gravity.

- Easy to maintain and repair

  A system that cannot be repaired is of little to no use of the Navy. A system is needed that can last a number of years and remain up to the same quality as when it was initially installed. The ease and cost of repair and maintenance is also vital since this will not be a system that is constantly in use, it should not be a system that is constantly being repaired.

- Requires little power

  The power required to run the system is an item to keep in mind while developing a concept. The system is meant to have the capability to be implemented while the vessels are moving. This means a great deal of the power is going to be devoted to the main engines to propel the ship. The system designed needs to run off of small amounts of power as to not compromise the amount needed to run the actual ship.

- Must be easy to train men to operate

  Training soldiers is a process that takes lots of time and money. These are two quantities not readily available. The system needs to be designed such that it would require the least amount to time to train men to use. The system should be as intuitive as possible. This is related to the requirement that the system be automated.

- Must be as simple as possible

  The more complex a system, the more likely it is to be costly to make, costly to repair, and easy to break. Complicated elements need to be replaced or rethought if simpler mechanism will do. The simplest system possible system should be designed with out compromising safety.

Once these requirements were decided upon, a weight matrix was made (Appendix A). A weight matrix is one that allows requirement to be ranked in order of importance by comparing each criterion to each of the remaining criteria. Each item was to be judged against another criteria one at a time (such as Safety vs. Transfer rate). If safety is more important than transfer rate, safety would receive a plus one, equally important would receive a zero, and less important would receive a negative one. These ratings were then summed up, creating a total of 182 points for the entire system. The total points, which each requirement received, were then divided by the total over all points to come up with a percentage of worth. The requirement with the highest percentage is the most important for the system to fulfill and the requirement with the lowest percentage is the least important. The weighting system is as follows:

Requirement	Percent Weight
Safety	14.58
Transfer Rate	13.02
Functionality at Sea State 4	12.5
Complexity	8.33
Maintenance	8.33
Rapid and automated	7.81
Retro-fit	7.29
Transport with packs	7.29
Protection from Environment	6.25
Weight/ Size	5.73
Storage	4.69
Power Required	3.13
Training	1.04

Table 1.5.1: Requirement Weight Table

1.5.3. Decision Process

Using the requirement weight rankings, two decision matrixes were developed. The first matrix was very basic and was used as a means of weeding out ideas that did not warrant further development. The matrix was made up of 8 questions which were answered on by a “Yes”, “No” or “Maybe.” These questions were as follows:

- Could the system be safe for the troops?
- Could the system be functional at sea state 4?
- Could the system be easy to retro-fit to previously existing ships?
- Could the system be rapid and automated?
- Could the system be low in cost?
- Has this idea be already been done?
- Is it worth further looking into this idea?

Only 6 ideas received a “Yes” to the final question. These ideas were then further researched and developed. The ideas were: JHSV, SWATH, spar ships, blimps, gondolas, and bridges/ramps/tunnels. A list of pros and cons for each idea was developed by the team. This list allowed the team to create potential solutions to problems before they occurred during the design process.

Following the creation of this list, more detailed descriptions of each of the concepts were formed. Using these descriptions, a more in-depth decision matrix was developed. The matrix graded each idea on a scale of 1 to 10 using each of the 15 requirements.

	Weight	JHSV + sys.	SWATH + sys.	Blimp	Spar Ship	Gondola	Bridge/Ramp
Safety	0.146	10	10	4	8	5	8
Transfer Rate	0.13	8	8	5	8	6	9
Functionality at Sea State 4	0.125	8	8	9	10	8	9
Complexity	0.083	--	--	7	3	7	4
Maintenance	0.083	--	--	4	5	4	4
Rapid and automated	0.078	--	--	3	5	3	6
Retro-fit	0.073	1	1	8	1	8	7
Transport with packs	0.073	10	10	7	10	7	10
Protection from Environment	0.063	10	10	6	3	5	8
Weight/ Size	0.057	--	--	3	1	7	6
Storage	0.047	--	--	8	1	8	4
Power Required	0.031	--	--	8	4	7	8
Training	0.01	--	--	4	3	6	6
Total:		4.93	4.93	5.82	5.76	6.13	7.18

Table 1.5.2: Idea Rating Table

At this point in the design process, the Rope Bridge/Tunnel idea emerged on the top of the list. The remaining 7 ideas were then broken down into vessels and processes. The blimp idea is ranked third, but when a quick feasibility study was conducted it was determined that the blimp would have to be very large and therefore unfit for further development. The remaining 3 processes, rope bridge, gondola and spar ship, were accepted as the ideas which would be kept and further developed.

1.5.4. Further Development

For each idea, following the decision matrix, a 3-dimensional image was created. The models allowed for the group to get a physical grasp on each of the systems as well as create a rough structural model from which a final product could be developed. As each step of the design cycle was completed, an updated version of the system was developed.

A brief event model was then written about each idea. This model was made up of the individual steps required to implement the system. This would include retrieval from storage, set up, usage, take down and storing. A rough estimate of the time frame needed to implement the system was included. This time frame was made one the assumption that each step would be done individually.

Calculations for each design were then carried out. The most important calculations were throughput rate, weight and size. Force calculations were done for the systems on an elementary level. Due to the fact that the systems consisted of recently developed synthetic and composite material, not all properties were available for detailed calculations. Also, the systems themselves

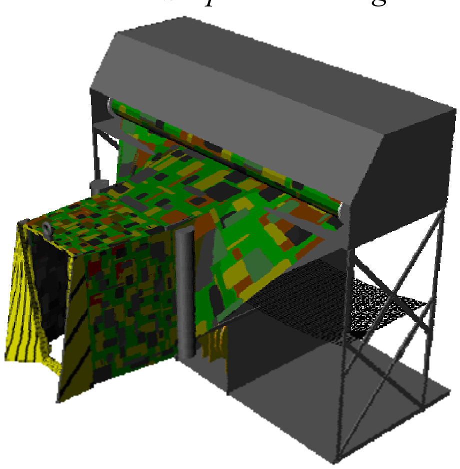
were complicated limiting the amount of calculations that could be done with no known forces or moments.

Following the calculations, necessary changes were made then a final design was decided upon. A detailed 3-D image as well as a detailed description was created of each design. Once finalized, the team came up with ideas for further improvement and development of each system. Do to time limits there were some area of development that could not be completed as well as desired. Also, for improvement of the over all design, certain elements of each concept could be further developed by more qualified, knowledgeable individuals. The potential areas for improvement are mentioned in each concept's specific section in the report.

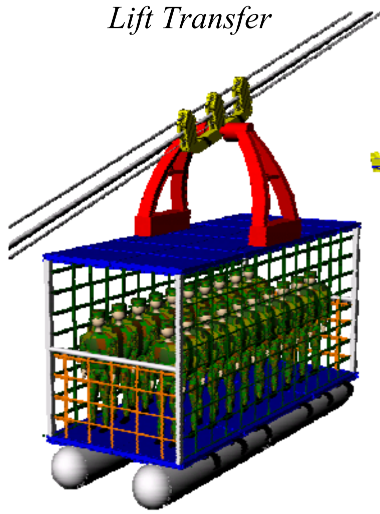
2. Central Concepts

Due to the time constraints of this project, there was not enough allowed time to be confident in deciding on which idea would be the best solution. Consequently, the focus could not be narrowed down to one concept. As a result, three ideas were chosen to be pursued from the list of brain storming concepts by using the decision charts described in section 1.5.3. These ideas were the *C-CaSBr*, the *ASPALT* and the *PTS*.

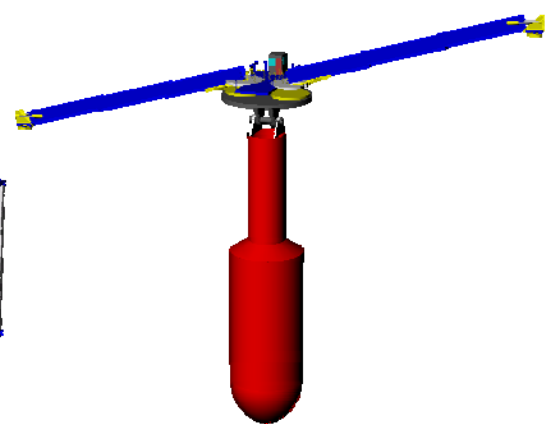
Covered Cable Suspension Bridge



At Sea Personnel Aerial Lift Transfer



Personal Transfer Spar



3. *C-CaSBr* - Design description

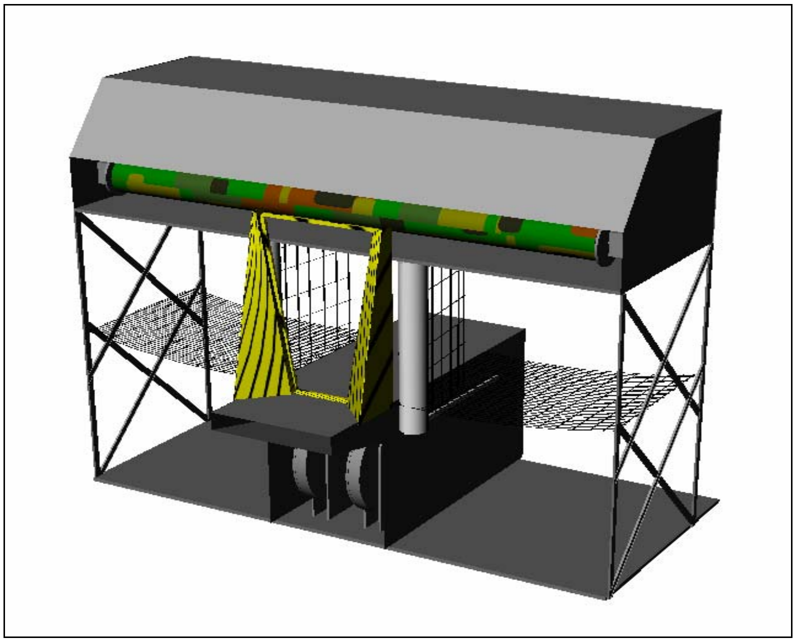


Figure 3.0.1: The *C-CaSBr*

The Covered Cable Suspension Bridge (*C-CaSBr*) is a sophisticated form of a rope bridge that was chosen because of its flexible nature and ability to absorb torsion. The rugged design of the system would allow for protection against the weather during transfer as well as a long life. Major benefits to the bridge are that it is light weight, variable in length, small in size and easily retro-fitted to existing ships. The *C-CaSBr* would consist of four support cables, two hand guide wire cables, canvas, flooring, safety nets as well as various motors and reels.

Item	Measurement
Length of System	200 feet
Weight of total system	1217 lbs
Material for Cables	Plasma 12x12
Material for Cover	Canvas
Material for Flooring	Composite
Diameter of cable reel	29 inches
Width of cable reel	22 inches
Cable reel motor	24 VDC
Diameter of canvas reel	1.0706 Feet
Core diameter of flooring reel	5.5 inches
Throughput rate	300 men/hour

Table 3.0.1: Basic *C-CaSBr* Specifications

3.1. Evolution of Concept

The *C-CaSBr* evolved from a basic rope bridge found in most playgrounds and outdoor hiking trails. In such bridges, the structural support comes from two cables which are placed a certain width apart and run parallel to each other for the entire span of the gap. Planks are set on top of these support cables and tied into place to create flooring on which to walk. Typically, there are two guide cables at waste height above the main support cables, used for hand railings. These guide cables are connected to the support cables by vertical ropes which are tied at each end. This creates at small fence along the lower half of the bridge.

To start the design process, the two guide wires were replaced by one cable which was raised from approximately 3 feet to 8 feet from the floor boards. By doing so, the cable was able to be utilized as a load bearing cable, allowing for more flexibility in the rest of the design because more weight could be supported. Instead of ropes connecting the guide wire to the bottom two support cables, canvas was draped over the top cable to create a triangular tunnel. This modification was made to create a shield from the environmental elements. All of the materials (the cables, flooring and canvas) were designed to be rolled up on specialized reels stationed on the ship sending troops. Originally there were three rolls of material, one for each side of the triangle as seen in figure 3.1.1.

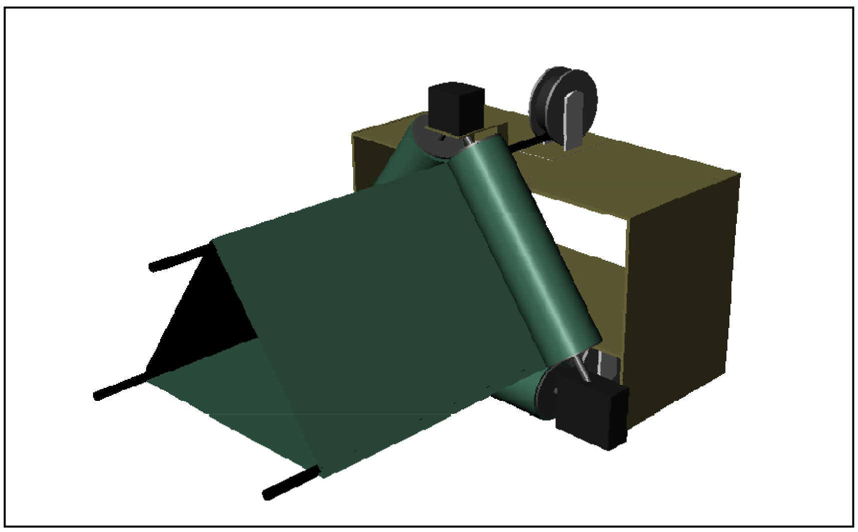


Figure 3.1.1: Evolution of design; Stage 1; Triangular Tunnel

There were three cable reels placed at the appropriate heights on a structure located on the delivery ship. By having each spool of material and cable attached permanently to a structure, it would cut down on the time require for set up and take down of the system.

The next modification in the design was to change the shape of the tunnel from triangular to trapezoidal as seen in figure 3.1.2.

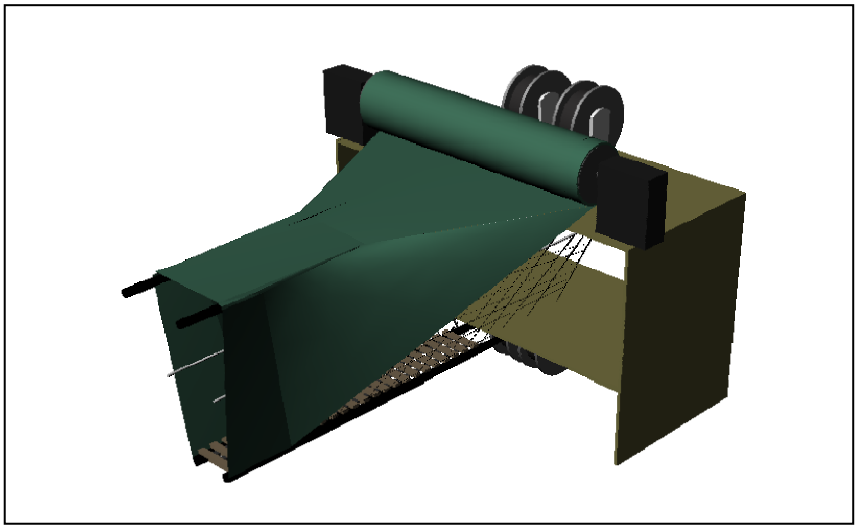


Figure 3.1.2: Evolution of Design; Stage 2; Trapezoidal Tunnel

This was to account for shoulder room required for both the marines and their packs. The cables on the floor of the tunnel were placed closer together, roughly two and a half feet apart, to minimize the flooring material needed with out reducing the stability. The cable running along the top of the tunnel was replaced by two parallel cables with twice the distance between them than the current floor cables. Instead of having three rolls of material (one for each side of the tunnel), the canvas was placed on a single long spool. This would decrease the number of motors and moving parts required to run the system. The canvas would be made into the shape of a trapezoid by using to rollers to bend the fabric corners down as it is being dispensed off the roll.

Following the development of the new shape and structure layout of the system, materials were researched for each of the individual elements. For the cables, two main materials were considered, steel cable and synthetic fiber. The benefit to steel is that it is a strong, easily available material that soldiers are already familiar with. However, steel cable is extremely heavy and thick. This would cause major problems with the design due to weight and size constraints. Synthetic fiber rope is equally as strong as steel cable but drastically lighter in weight. However, it is considerably more expensive than steel cable.

The covering of the tunnel, for cost purposes, was made out of one material. This would mean the sides and ceiling could, in fact, be a continuous piece, stored on a long spool. The two material options were loose cargo net or a canvas material. The cargo net concept had the benefit of being very light weight. Unfortunately, lack of protection from the weather eliminated this option. The alternative to netting was to use a canvas material. This material can be sealed with a weather protected material to ensure that water would not soak through the canvas.

For the flooring three main options were researched. The first used a type of wire/cable mesh that would be directly connected to the two main support cables (Figure 3.1.3).

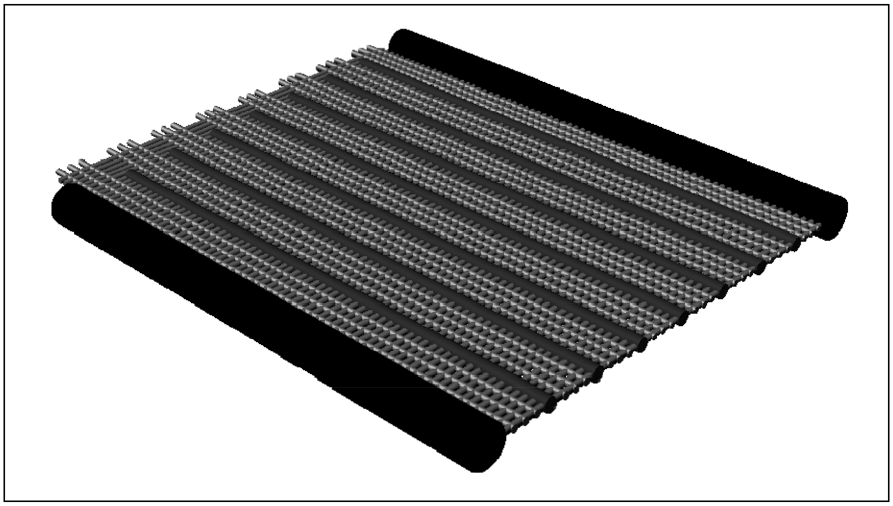


Figure 3.1.3: Evolution of Design: Mesh Flooring

This mesh would consist of a number of cables which would run perpendicular to the support cables and be half the diameter. These cables would provide much needed support and reduce the amount of inward sage the cables would face. Woven tightly in and out of these cables would be much thinner wires that would create an almost solid mesh flooring. This system of interwoven cables would be dynamic and flexible but it would take up a large amount of room when stored (approximately a 9 foot spool). Also it would create heavy flooring which would cause a great amount of lengthwise sagging.

The second flooring option was to use thin steel plates connected by a fabric hinge (Figure 3.1.4).

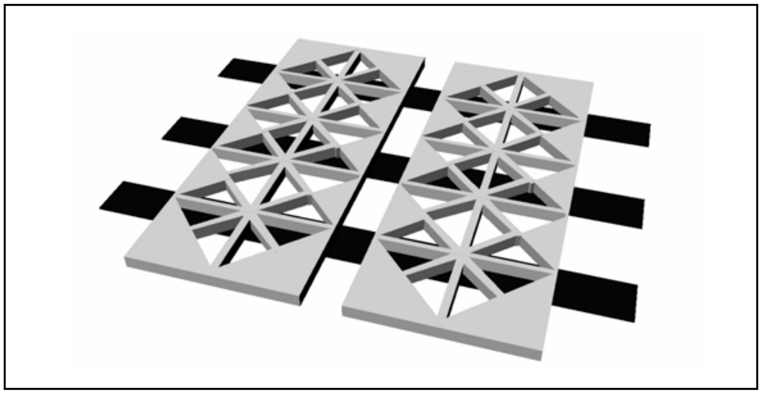


Figure 3.1.4: Evolution of Design: Metal Flooring

To reduce the weight of each plate, triangle cut outs would be made, taking out half of the material, but keeping much of the strength in tact. Using fabric hinges would allow the system

to be rolled up easily, and be much lighter in weight than steel or metal hinges. The problem with using fabric hinges is that connecting the fabric to the steel would create a weak joint with in the system. Also, even with half the weight cut out of the plating, the overall flooring would be the heaviest option out of the three ideas.

Composite flooring was investigated for the third option; more specifically, polypropylene co-polymer flooring (Figure 3.1.5).

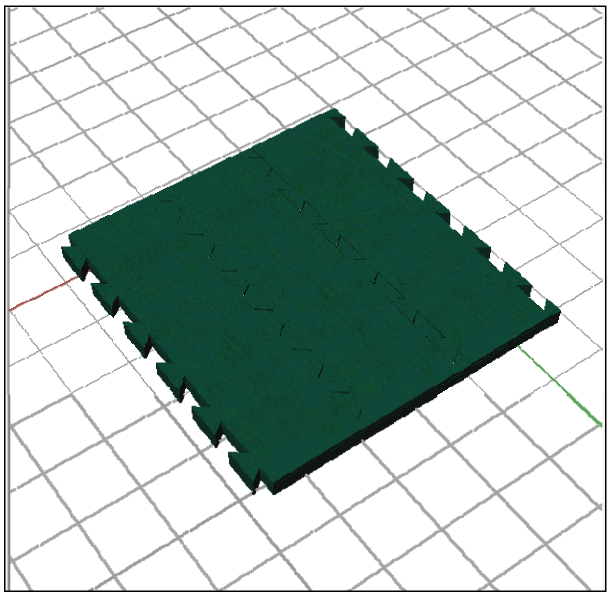


Figure 3.1.5: Composite Flooring

This particular type of flooring is currently used in a wide variety of applications, but most commonly for field covering for events. The appealing characteristics of this particular type of flooring are that it is lightweight and designed so it can be rolled up. The joints on the sides of each panel are dovetail joints and can be rotated up to 90 degrees (with respect to the connected panel) with out separating. The flooring typically comes in planks of 4 inches by 12 inches, so special sized pieces would need to be manufactured for this particular application.

3.2. *Detailed Description*

A. Canvas on Reel
B. Upper Compartment
C. Safety Netting
D. Loading Platform
E. Receiving Frame
F. Lower Cable Reels
G. Canvas Rollers

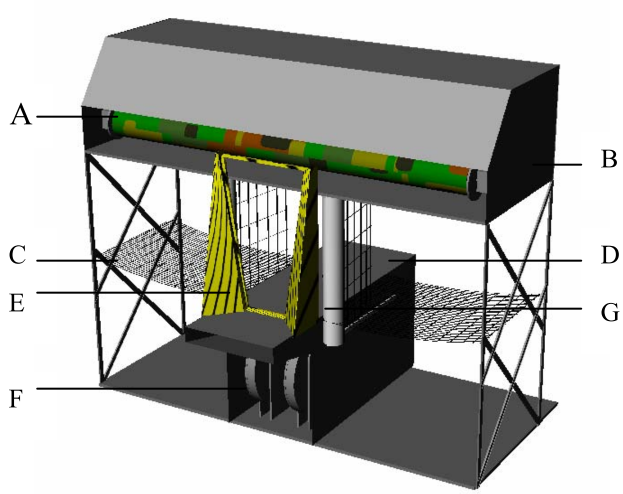


Figure 3.2.1: Stored Set Up of the *C-CaSBr*

Item	Measurement
Weight of cables	525.6 lbs
Weight of canvas	286.6240lbs
Weight of flooring	405 lbs
Weight of total system	1217 lbs
Core diameter of cable reel	4 inches
Diameter of cable reel	3.4067 feet
Core diameter of canvas reel	3.5 inches
Diameter of canvas reel	1.0706 Feet
Core diameter of flooring reel	5.5 inches
Diameter of flooring reel	4.0157 feet
Vertical reaction forces at lower cable reel	324.45 lbs
Vertical reaction forces at upper cable reel	137.36 lbs
Throughput rate	300 men/hour

Table 3.2.1: Calculation Output for *C-CaSBr*

On the parent, or delivery, vessel the final structure is intended to be permanently stationed on the uppermost deck. The footprint on the deck of the structure is 24.05 feet by 15.28 feet, with the length running parallel to the ship. Currently it is assumed that the structure will be fully above the main deck of the ship to minimize the amount of modification required on the actual ship while being retro-fitted with the system. When the structure is set up on the deck, it stands 20 feet tall.

The main structure of the system consists of an upper cable/canvas cover, a lower cable cover and side support framing. The upper cable reel and canvas cover (B) is 6 feet tall, 8.35 feet wide and spans the length of the structure. This compartment is designed to act as protection for the cable and canvas reels as well as the materials.

There are two cable reels housed in the upper compartment. Reels similar to those produced by ReelCraft® were used in the design. The large frame reels are series 40 models having a drum with a diameter 11.25 inches and a length of 22 inches. The over all height of the reel frame is 29 inches with a width of 33.75 inches (including motor). Reels are outfitted with either a 12 or 24 volt DC motor delivering 1/3 hp, an explosion proof motor delivering ½ hp, an air motor delivering up to 4 hp or a hydraulic motor. All the powering options are reversible and are compatible with the standard weather resistant starter switch. These motors are used to assist the unreeling and reeling in processes.

The canvas is also on a similar reel set up in-housed in the upper compartment. Custom reeling systems would be needed for the canvas since standard lengths typically do not exceed 30 inches. In the diagram above, the canvas (A) is shown in a camouflage print strictly for purposes of distinction. The canvas being used for this model is treated with a weather resistant coating which will act as a sealer to prevent water from soaking into the canvas. For every 1 square foot of fabric, two 2.5-inch diameter holes will be cut out allowing wind to travel through the side walls and ceiling of the tunnel. By doing so, it prevents the tunnel from acting as a large sail and causing major torsion issues within the system. Also, by removing small circular sections, the weight of a square foot of fabric is reduced by almost 7%. When 200 feet of canvas is wound on a reel with a core diameter of 3.5 inches, the outer diameter measures 1.0706 feet.

Connected to the canvas will be the hand guide wires. These are small wires at about waist height which soldiers will be able to loosely hold on to while using the system. These wires are not meant to be load bearing wire, nor support for the system. They are merely there to aid in the balance of the soldier using the bridge.

Connected to the underside of the upper compartment are guide rails for the canvas rollers and half of the safety net system. These guide rails allow the rollers and netting to be retracted while the system is not in use, saving valuable space. Similar rails are on the lower side of the rollers and netting as well, connected to the side of the loading platform. Instead of connecting the rollers and netting to a motorized system, they will be able to slide along the guide rails by pushing and pulling them, and then locked in place. This cuts down on the amount of motorized components and possible systems to maintain.

The canvas rollers (G) are two 1-foot diameter rubber cylinders with a height of 8.2 feet. They are tilted at a nine degree angle from perpendicular with respect to the upper compartment. This tilt is at the same degree as the desired angle for the canvas, allowing the bottom edge of the canvas to be attacked to the floor planks using industrial strength snaps by pressing them in place.

The safety netting (C) is in place so that, when in use, there is no gap between the loading platform and the beginning of the tunnel into which one could fall. This netting is a loose cargo and is also used horizontally between the loading platform and the vertical beam supports.

The loading platform (D) is a compartment to cover the bottom two cable reels (F) (identical to the upper reels) and the spool of planks for the flooring. The top of the compartment is used as a platform to stand on and leads directly into the tunnel. The opening on the compartment is tapered so that the bottom cables and the flooring planks get pushed together as they extend out.

The planks for the flooring are a polypropylene co-polymer composite. This material was chosen over both steel and mesh flooring because it has the most ideal balance between weight and strength. This material weighs 0.81 lbs per square foot which is 0.675 lbs per plank (Signature Systems). The planks are 2.5 feet wide, 4 inches wide and ¾ of an inch thick (Figure 3.1.5). Semi-circular groves are cut in the bottom of the planks so that they can be set directly on top of the bottom two supporting cables. The planks are designed with dovetail joints so they can be bent at a 90 degree angle at the joint and not separate from each other. The composite is water proof and could potentially be coated with rubber for better traction when wet. The reel on which the flooring is wound has a core with a 5.5-inch diameter. When fully wound, with 200 feet of planking, the spool has a diameter of 4.0157 feet.

While the unit is in the storage state, the receiving frame (E) sits on top of the loading platform. The receiving frame is a steel casing with an inner most structure that matches the shape of the tunnel. A more detailed view of the frame can be seen in figures 3.2.2 and 3.2.3.

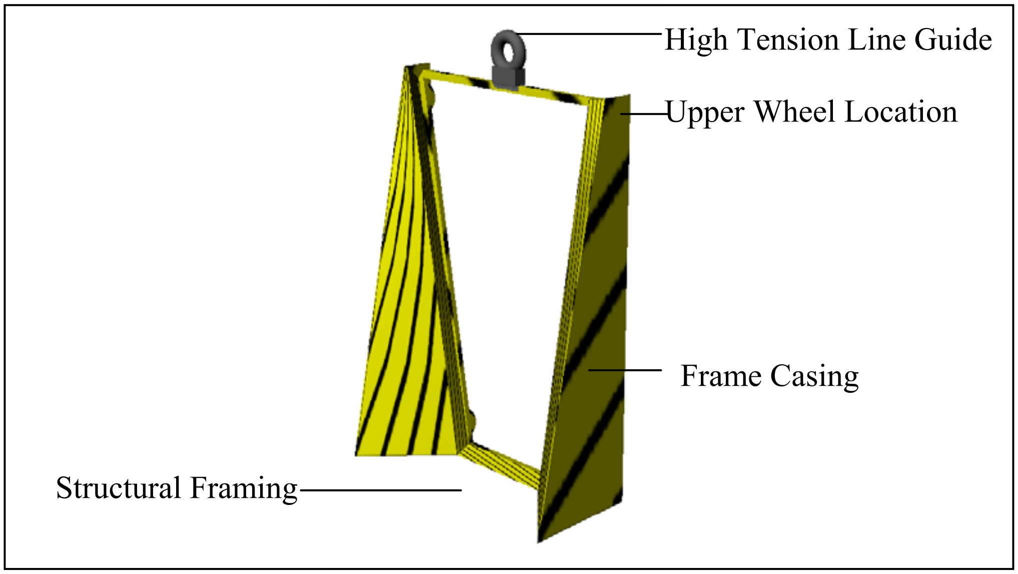


Figure 3.2.2: Receiving Frame Diagram

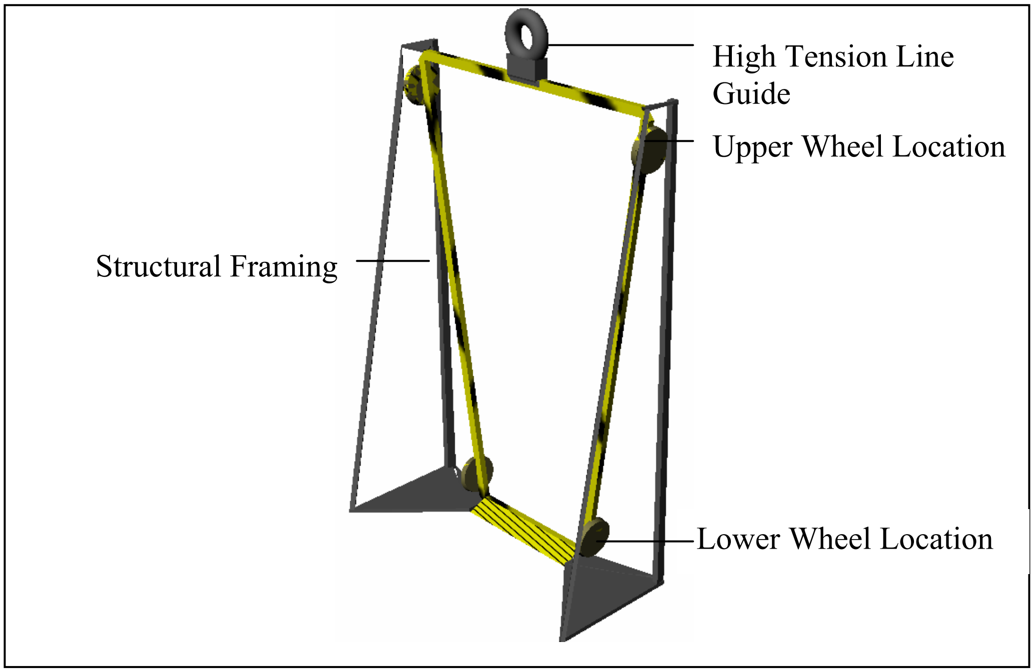


Figure 3.2.3: Receiving Frame with Casing Removed

Inside the casing there are 4 plastic wheels, one in each corner. The wheels are connected to the frame using rods running parallel to the ship's deck. Loops at the ends of the cables are placed around theses wheels allowing for the cables to pivot freely, automatically adjusting for change in angles.

At the end of the cable loops is a section of cable designed to act as a shock absorber. This allows sudden changes in tension on the cables to not adversely affect the overall stresses in the entire systems. Similar shock absorbers are found on the upper cables and canvas as well.

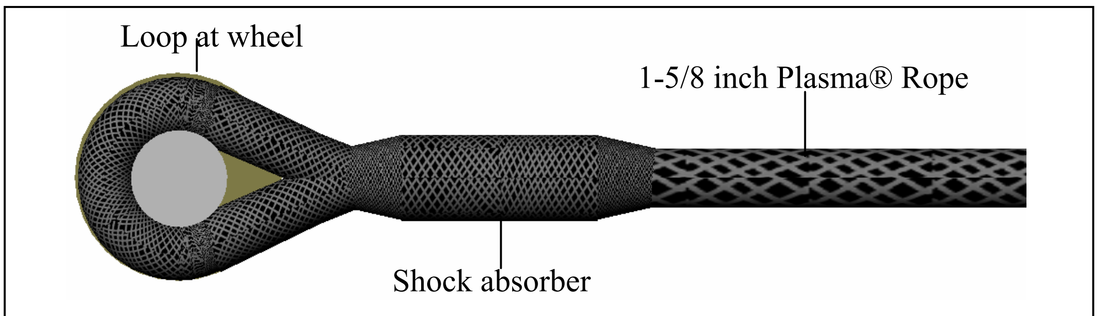


Figure 3.2.4: Rope Set Up at Connection to Frame

The cables on both the top and bottom of the tunnel are synthetic fiber cables. More specifically they are 1-5/8 inch 12x12 strand Plasma® rope (Puget Sound). This particular cable is high in strength and low in weight. The major benefit of using such a cable is that the weight of the over all system, when compared to using steel, decreases by 90%. Two hundred feet of

Plasma® rope weights a mere 131.4 lbs where as steel cable of equal diameter weighs 1410 lbs. The Plasma® rope has a tensile strength of 291,000 lbs which is within the approved ABS and DNV limits (Puget Sound). The rope is easy to splice, torque free, and it floats.

To assist in the constant tension process, a set of tensioners will be needed for, as a minimum, the bottom two cables. These tensioners will take into account the roll motion of the two vessels involved, allowing for the extension and retraction of the cable as needed. Currently, the ram tensioners in use are too large for this application, so the practicality of the design depends on the development of a smaller system. For the flooring and canvas reels, a set up similar to that of a seatbelt will be used. The flooring or canvas would be easily deployed when the cables are extended. When the material needs to be rewound, a spring will allow the spool to wind up rapidly.

While being stored, the canvas and cable reels, receiving frame, safety netting and canvas rollers are locked into place so they won't unravel to shift while the ship is in motion.

3.3. Event Model

The following is a set-by-step process for the use of the *C-CaSBr*. The times are rough estimates. It has been assumed that the system will be able to utilize the methods similar to that of the underway replenishment process to guide the extension of the system from the sending ship to the receiving ship. The steps require to start the underway replenishment process have therefore not been added to the event model. The start of the event model takes place once the tensioned highline has been passed to the receiving ship.

Event Model of *C-CaSBr* (Assembly)

Step	Procedure	Time (minutes)
1	Attach guiding loop on receiving frame to highline.	2
2	Unlatch safety locks from receiving frame, canvas reel and cable reels.	3
3	Attach cable loops to wheels on receiving frame. 3.1: Remove outer side plating on outside of receiving frame. 3.2: Remove outer half of wheel. 3.3: Slide each cable on its respective wheel rod. 3.4: Reattach outer half wheel. 3.5: Reattach side platting on receiving frame.	5
4	Attach canvas to receiving frame on all sides.	3
5	Extend canvas rollers and safety netting.	2
6	Lock canvas rollers and safety netting in place.	1
7	Manually push the receiving frame, with attached components, through canvas rollers.	2
8	Engage motors associated with each cable reel, canvas reel, and flooring reels.	2

9	Check all connections for safety.	2
10	Release cables, flooring and canvas by having each motor at the same speed. The tensioned highline through the top of the receiving frame will act as a guide for the tunnel as it is being passed from the sending ship to the receiving ship. During this stage, the canvas will be in the process of being attached to the floor planks by the canvas rollers. As the cables, flooring and canvas is released from the respective reels at a controlled rate, the rubber rollers will not only guide the canvas into the correct formation, but will apply enough pressure to engage the industrial snaps, connecting the canvas and flooring.	10
11	Once receiving frame has reached the receiving ship, the frame is to be bolted on to the ship deck.	
	11.1: Remove all side plating from receiving frame.	
	11.2: Using 7 bolts (three along each side and one in the center) attach the frame to the deck.	5
	11.3: Reattach side plating to receiving frame.	
12	Stop all motors and lock in position.	1
13	Check all connections for safety.	2
14	Send troops across by foot.	
	Total assembly time:	40

The time indicated as the total assembly time is based on a sequential completion of each step. Steps can be done simultaneously to reduce assembly time significantly. This particular event model is meant to describe the steps needed to go from high ship to lower ship. The process is possible from low ship to high, by making the adjustment at step 10 by adding motorized winches.

To disassemble the system:

Event Model of *C-CaSBr* (Disassembly)

Step	Procedure	Time (minutes)
1	Engage motors associated with each cable reel, canvas reel, and flooring reels.	2
2	Unbolt the receiving frame from the receiving ship.	
	2.1: Remove all side plating from the receiving frame.	
	2.2: Remove all 7 bolts from decking.	5
	2.3: Reattach side plating to receiving frame.	
3	Set the directions of the motors reverse to the assembly process.	1

4	Winch in the cables, flooring and canvas at the same rate. As this is occurring, the force the canvas reel is exerting on the system will disengage the snaps, releasing the canvas from the flooring.	10
5	Once the receiving frame has reached the sending ship, disengage motors.	1
6	Pull receiving frame through canvas rollers.	2
7	Remove canvas from receiving frame.	2
8	Dismantle the receiving frame. 8.1: Remove outer side paneling. 8.2: Remove outer half of wheel. 8.3: Slide each cable off wheel rod. 8.4: Reattach outer half wheel. 8.5: Reattach side platting on receiving frame.	5
9	Retract canvas rollers and safety nets.	2
10	Detach guiding loop on receiving frame to highline.	2
11	Secure all safety latches.	2
	Total disassembly time:	34

3.4. Emergency Breakaway / Failure Scenario

There are various ways that the *C-CaSBr* could potentially fail. The first of which is receiving frame and high tension line, or supporting cables detach from the receiving ship. This may occur if the frame is not properly secured or if the bridge is overloaded. The reels would remain attached at the parent ship causing the materials to hang into the water. The men still inside the *C-CaSBr* would slide down the shoot and into the water. Because all of the materials chosen both float and are water proof, any excess material will remain at the surface of the water. If there is too much excess material on the surface, and men are still inside, the snaps which connect the flooring to the canvas can be disengaged allowing men to get out through the sides. From here, standard procedures for retrieving men from the water will need to take place.

There is the opportunity for failure to occur during the assembly stage. If the motor on a single reel or multiple reels were to fail the entire process would stop. Each reel is outfitted with an emergency stop switch with a master system. Once the motors on the reels are stopped the system can be run manually. The reels as attachable cranks which will allows the men to either rewind the system and correct the problem while it is in the storage state, or fully deploy the system and fixing the problem after use.

If the high tension line, or the guide for the line, were to break during the assembly process, the cable reel motors would need to be put into reverse. The system could be reeled back up with out the assistance of the guide wire, but could not be re-deployed until the line is fixed.

In the case where an emergency breakaway needs to occur, a few different approaches could be taken. If time permits, the casing of the receiving frame can be removed so that the loops on the end of the cables could be detached while intact. The canvas can be removed on the receiving end as well as the flooring. Once each component is detached from the receiving frame, it can be allowed to fall into the water. If there is not enough time to disassemble the receiving frame, the cables can simply be cut off of the frame. The same can be done to the canvas if there is not enough time available to detach it properly. If the material were to be cut off the frame, the entire system would not have to be replaced. A benefit to the cable chosen is that is it relatively easy to splice in a new section. This will allow the cable to be repaired at a fraction of the cost as compared to replacement. The same can be done for the canvas using industrial strength threads and machinery to make the repairs. If the break away needs to, for any reason, occur at both ends of the *C-CaSBr*, the material can be cut off in a similar fashion as stated above. The recovery of the material would be fairly easy considering all the material is made to float.

3.5. Future Direction

One area that needs further development is the motors required for the system. For the *C-CaSBr* design to work, a network of simultaneously rotating reels would need to be kept in sync with one another yet be powered by separate motors. The size and weights of the motors would be based around the forces necessary to push out and pull up all of the cable, canvas and flooring elements. It was not in the team's time line, to develop an accurate prediction for the required power source necessary.

Another aspect for further development is storage. Currently the system rests on the deck of the sending ship. However, it would be ideal if the system could be stored below deck and only brought out when needed. One option to consider that would reduce the size of the system for storage would be to break the canvas roll into three separate pieces that are some way connected as they are unrolled. Breaking the long canvas roll up would allow for the system to fit into a standard shipping crate assuming other parts of the system could be broken down as well.

An option that was briefly considered was placing the cable reels and the flooring reels in a horizontal configuration. This would reduce the height of the over all structure. The main problem with this idea, and the reason why it was not further investigated, was the flooring. If the flooring reel were placed on its side, the panels would need to rotate 90 degrees in the distance from when it comes off the roll to when it is being used. With out separating the planks from each other, this idea is very difficult to launch.

If a collapsible structure could not be developed, other decks could be used as a point of origin for the system. This may increase the amount of work required for retro-fitting, but it would decrease the angle between the receiving and delivery vessels, creating and easier walk. This maybe a worth while modification for the Navy to invest in if this idea were to be used on a consistent basis.

Creating a specific system for the sending of the receive frame might also be worth

investigating. Currently it is assumed that the tensioned high wire will act as a guide for the frame as it is in a controlled slide from one ship to the other. A more precise system would decrease the amount of error that could occur during the process and may increase the speed at which the system would run. A system of cranes may be a solution to this problem by simply picking up the frame from the delivery vessel, and placing it on the deck of the receiving vessel. An alternative solution may be to toss the frame in the water and drag it to the receiving vessel. If the frame was made out of titanium instead of steel, this may be a reasonable.

The tension systems needed to implement this design require further research. Currently it is assumed that shock absorbers at the ends of each cables and on the canvas will be enough to keep the entire system in constant tension. Similar shock absorbers are currently in use in mooring lines for personal ships as well as some commercial ships, but a custom design would be needed for the *C-CaSBr*.

With the exception of the industrial snaps, items such as latches, locks, bolts and hooks for the canvas to floor attachment, were not developed because of the complexity of the mechanism. Although the snaps were accepted in the final solution for connecting the cables and flooring, some alternatives need to be investigated.

The planks are currently just resting on the cables and are not attached in any way; this is a problem that will need to be resolved for the system to be practical. An idea was to create a magnetic strip along the inside edge where the cable currently rest. If a similar strip was placed either on the outer surface of the cable, or in the core of the cable, it would easily connect to the planks. Another idea was to incorporate the cable directly into the planks. The major problem with this idea is that the reel, when rolled up, with both the cable and planking would be nearly 9 feet.

With the necessary changes, a bit of further investigation, this idea could be a practical, light weight, relatively small solution to the problem of at sea personnel transfer.

4. *ASPALT* - Design Description

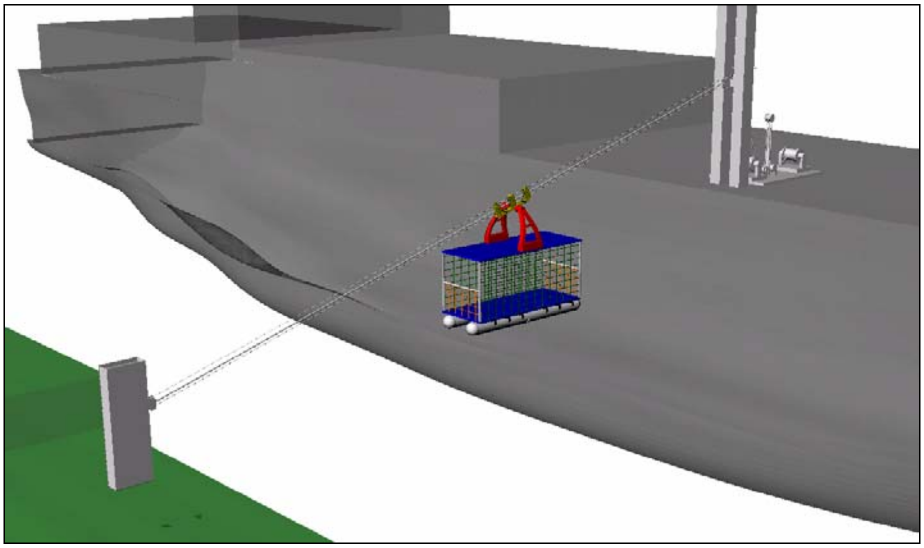


Figure 4.0.1: *ASPALT* in transit

The *ASPALT*, which stands for At Sea Personnel Aerial Lift Transfer, is chosen for its rugged reliability and ease of adapting to current methods of vessel to vessel wire transfer. Its major benefits include its compact size, simple operation, and lightweight structure. The idea of *ASPALT* stems from the current method of wire transfer between two vessels and would continue to use the current system. The base is made of a metallic alloy or composite combined with an inflatable structure underneath and is able to support the weight of 20 occupants and their equipment. The netting is flexible for easy storage as well as offering support for the occupants inside. The roof structure is made of a lightweight metallic material and provides a stable platform for the wire housing. The housing is fixed on to the inhaul wire which is driven from the delivery vessel. This method would require the delivery vessel to be outfitted with a winch to drive the wire while the receiving vessel would be outfitted with pulleys.

Item	Measurement
Length	20 feet
Width	8 feet
Height	19 feet
Number of occupants	20
Material options	Stainless Steel (304), Ti Alloy, Al Alloy, and Carbon Fiber (High Density)
Tare Weight (empty)	1124 lbs – 4958 lbs
Total Weight (including 20 personnel)	7424 lbs – 11258 lbs
Velocity	15 feet/second
Throughput rate	442 men/hour - 457 men/hour

Table 4.0.1: Basic *ASPALT* Specifications

In table 4.0.1 the ranges in weight are due to the fact that there are many materials suitable for this design.

4.1. Evolution of Concept

A current method of transferring supplies and occasionally personnel at sea is a wire system known as STREAM CONREP (Standard Tensioned Replenishment Alongside Method Connected Replenishment). STREAM CONREP requires vessels to send a series of wires between each other when the vessels are parallel to one another. A highline wire is tensioned in order for supplies and personnel to remain above the sea surface between two vessels while the outhaul and inhaul wires move in a loop. This system can handle loads up to 5700 lbs in sea state 5 and 10,000 lbs in sea state 3 (Strohman) between vessels up to 160 feet apart at rates of 15 feet/second to 133 feet/second (Tschiegg). Examples of U.S. ships capable of conducting UNREP (Underway Replenishment) are in table 4.1.1.

UNREP Ships	
Oilers	Cimarron (AO -177)
	Henry J Kaiser (TAO -187)
Ammunition Ships	Kilauea (TAE - 26)
Combat Stores Ships	Mars (TAFS - 1)
	Sirius (TAFS - 8)
Fast Combat Support Ships	Sacramento (AOE - 1)
	Supply (AOE - 6)
Aircraft Carriers	CV / CVN
Amphibious Assault Ships	LHA / LHD

Table 4.1.1: Ships Capable of UNREP (Mazat)

Alternate methods of at sea personnel transfer were presented in the October 2005 Sea Base Transfer of Personnel and Cargo (STO-PAC) report. One idea was known as the "Monorail Track and Carriage System (Anderson et al. 49)." It employed the use of a rigid cantilever beam, like that of a crane arm, with several carriages attached to it on a track that follows the length of the beam. These carriages would move around the beam delivering cargo and personnel to another vessel. Another concept involved a "Gator Crate (Anderson et. al 49-54)," which is a collapsible 20 feet ISO shipping container with an inflatable bottom that acts as a cushion. The Gator Crate would be equipped with seats for personnel to sit while the crate is lifted from vessel to vessel through the use of a crane. Although these ideas seem viable, they require vessels to be relatively close to each other as well as utilizing a crane or a rigid cantilevered beam among other devices.

The initial concept of the *ASPALT* first originated by observing ski lift and aerial lift gondola systems used to transfer people over rugged terrains at high rates. These systems can withstand extreme conditions while maintaining constant operation. They are also safe and reliable for its many users. Initially, the design was to convert an existing commercial aerial lift gondola cabin and adapt it to the current method of wire transfer. The cabin and its contents,

such as cables and motors, would be stored within a 20 feet ISO shipping container that would be kept on deck or in the hold of the delivery vessel. The benefit of this idea was most the equipment could be purchased "off the shelf;" however, it would make the *ASPALT* too bulky and cumbersome. The design needed to be more compact, less complex, and lighter.

The second stage of the design was to dismiss the idea of buying a commercial aerial lift gondola cabin and retro-fit it to the current method of wire transfer, but rather design an entirely new cabin as seen in figure 4.1.2. The concept stems from an apparatus used on oil rigs for personnel transfer (figure 4.1.1).

Figure 4.1.1: Oil Rig Personnel Transfer ("Safety First - Journey to Zero Accidents")

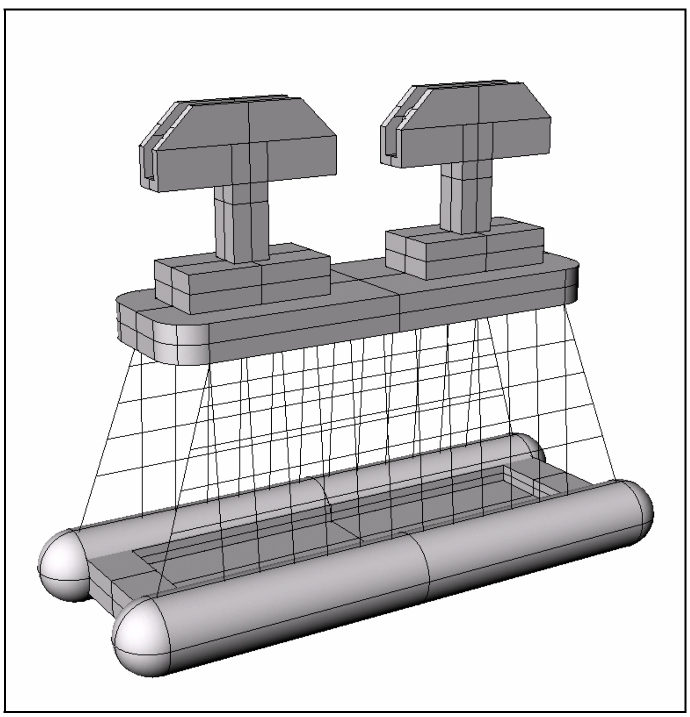


Figure 4.1.2: Second Stage Cabin Concept

The idea was to have the base *ASPALT* inflatable for easy storage and assembly, but strong enough to support the weight of 10 to 20 occupants and their equipment. The netting was a wire mesh and the roof made of a strong but relatively lightweight material. Initially the idea was to have the *ASPALT* motorized, and have the motors mounted to the roof. This design was lightweight and compact for easy handling, storage, and assembly. Instead of only having one supporting wire strung between two vessels, a second wire was added across the bottom of the *ASPALT* to provide extra stability while in transit, modifying the current wire transfer system. The problem with this design was if the system were to fail and fall in the sea, the entire roof unit would not be supported and collapse onto the occupants inside severely injuring or killing them. A second issue would require the motors that move this unit between the two vessels to be relatively small and lightweight. Also powering the motors became another concern with storage of fuel or the weight of batteries. Lastly this design is limited to personnel only, and could not serve a duel purpose of carrying heavy cargo. These issues hindered the design's versatile nature; therefore, adding versatility to the design required this design to evolve.

The third stage in the overall design evolution included a previously mentioned idea known as the Gator Crate. The general design of the Gator Crate was not be changed, rather modifications were made so it could be used for wire transfer as apposed to only LO/LO (Lift On Lift Off) applications proposed in STO-PAC. Having this configuration allowed the structure to be more stable and safer in high sea states while maintaining its lightweight, compact nature.

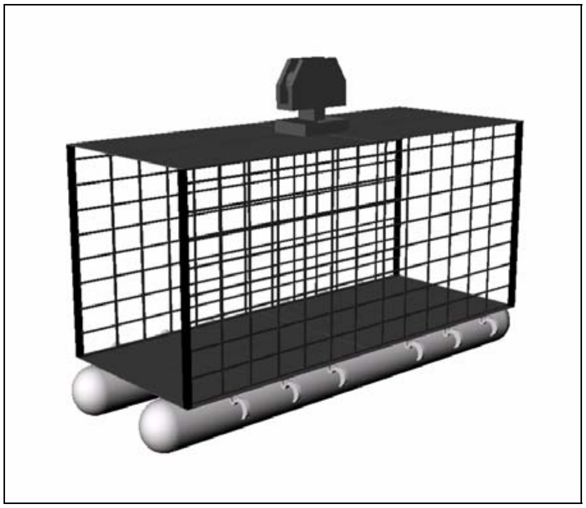


Figure 4.1.3: Third Stage Concept

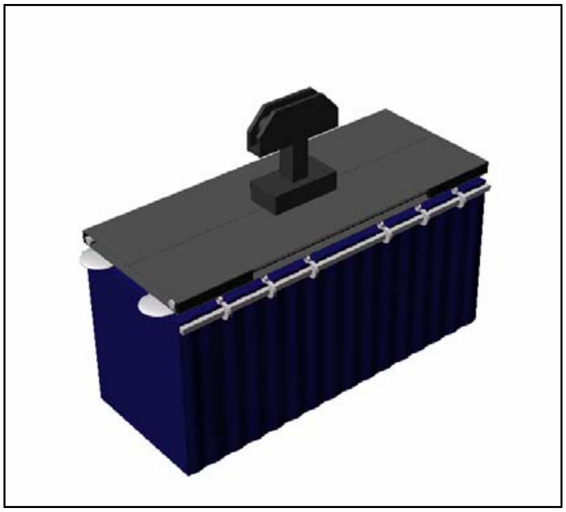


Figure 4.1.4: Third Stage *ASPALT* with 20 feet ISO shipping container

When the posts are collapsed and the support tubes deflated, the hooks, seen in figure 4.1.3 in grey, can grab onto a standard 20 ft ISO container as seen in figure 4.1.4.

Following the development of the Gator Crate aerial lift gondola hybrid, materials were researched for the base and roof in addition to the shape for the wire housing unit. Potential materials comprising the structure are stainless steel, titanium alloys, aluminum alloys, and

carbon fiber composites. The objective is to choose a sturdy lightweight material that does not decay in an oceanic environment. Also the size of the wire housing must be compact but strong to support the loads subjected to it.

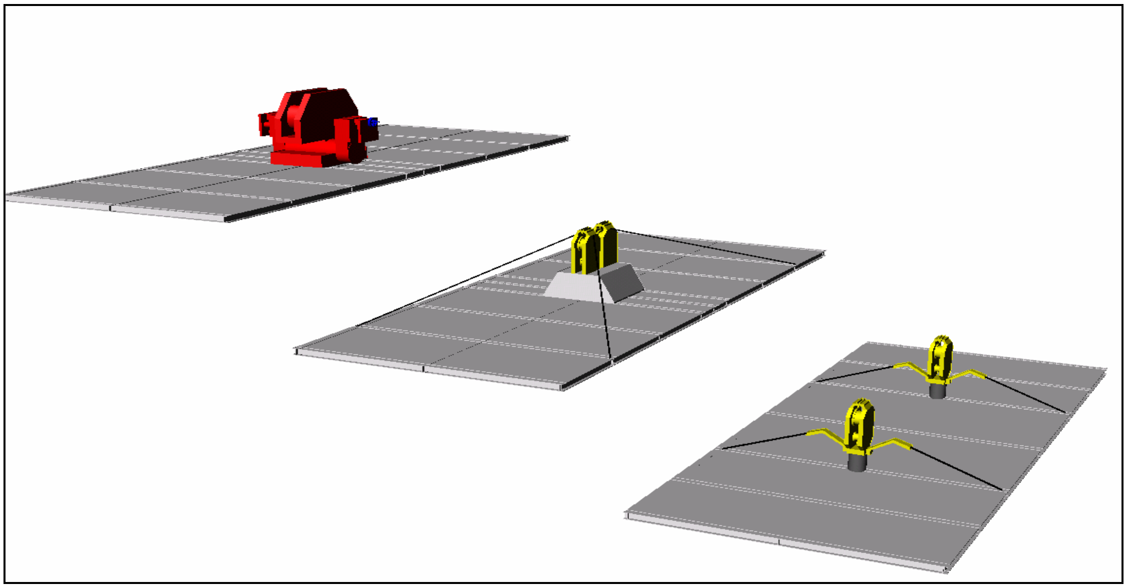


Figure 4.1.5: Forth Stage Potential Roof Structures

In figure 4.1.5 are three different designs considered for the wire housing, but dismissed due to the fact the wire housings will have the roof parallel to the wires strung between two vessels as in figure 4.1.6.

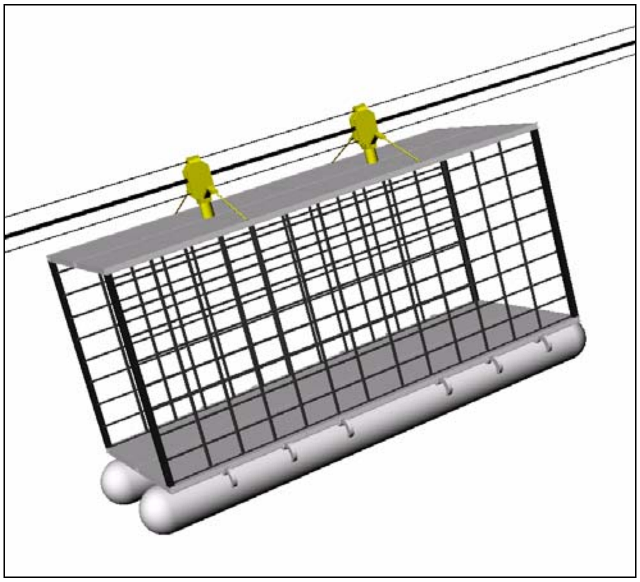


Figure 4.1.6: Forth Stage Appearance of roof parallel to wires

If the vessels are not the same height and the wires at sharp angles relative to the two vessels, between large vessel and small vessel, the occupants are not safe. At this sharp angle the

occupants would slide out at the lower end. Also the wire housing must be relatively high above the roof in order to allow the *ASPALT* to remain level in transit, and prevent the wires strung between vessels to not impact the sides of the roof structure. These issues are addressed in the final design.

4.2. Detailed Description

A. Inflatable Tubing
B. Base
C. Posts
D. Roof
E. Wire Housing
F. Rigging
G. Mesh
H. Gate
I. Hooks

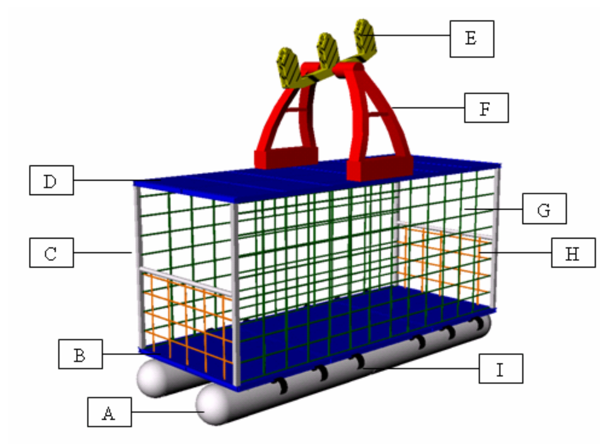


Figure 4.2.1: Legend for *ASPALT*

The *ASPALT* is not fixed into the deck in any manner. The posts (C) are hinged and fold in on themselves, for compact storage as show in figure 4.2.2 (Anderson et. al 51). The mesh (G) can fold down with the roof (D) or can be detached completely. The gates (H) are just netting to indicate the boundaries for the occupants inside. On each gate the netting is fixed on one end while the other end has a latch with the intention of being pulled aside for loading and unloading of personnel. The inflatable tubes (A) act as a medium to soften the impact of the *ASPALT* while coming to rest on deck. The tubes could also provide buoyancy to the structure if it were to fall in the sea.

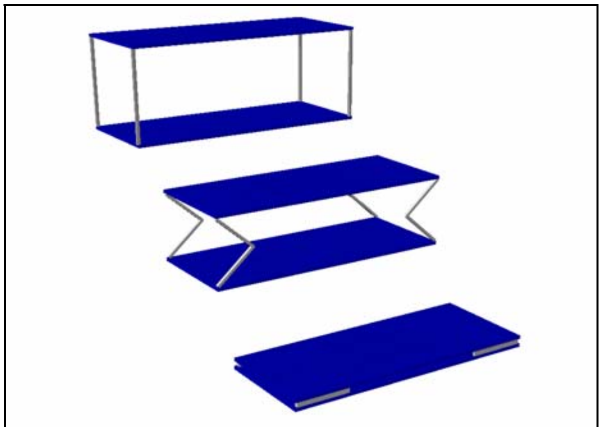


Figure 4.2.2: *ASPALT* folding process

The hooks (I) are present to grasp onto a 20 feet ISO container as shown previously in figure 4.1.4, serving a duel purpose for both personnel and cargo. The 20 feet ISO shipping container will have to be outfitted with a rod or latches on each side of the container for the *ASPALT* to lock onto. The rigging (F) is the support structure for the wire housing (E) which sits over the wires and is not powered by any means.

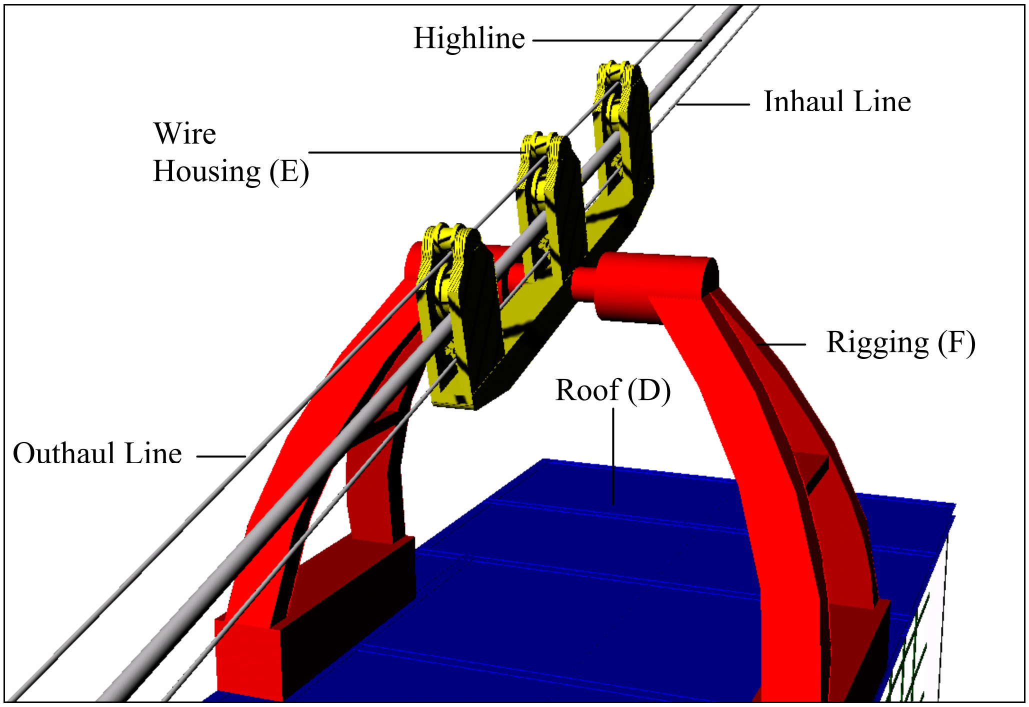


Figure 4.2.3: Diagram of line connections

The wire housing consists of three main parts: the inhaul grip, the highline pulley, and the outhaul pulley. The inhaul grip is a basic device that holds onto the inhaul line which allows the *ASPALT* to move at the same rate as the as the inhaul line. The highline pulley supports the majority of the *ASPALT*'s weight and is capable of rolling freely along the length of the highline. The outhaul line runs along the outhaul pulley as a means of closing the loop for the system.

The roof (D) and base (B) are constructed out of metallic I-beams as a means to reduce weight while keeping strength and rigidity as shown in figure 4.2.4. On top of the base frame is a 0.125 inch piece of metal or a composite of an undetermined thickness while the roof has the option of a durable canvas or lightweight composite to cover the occupants.

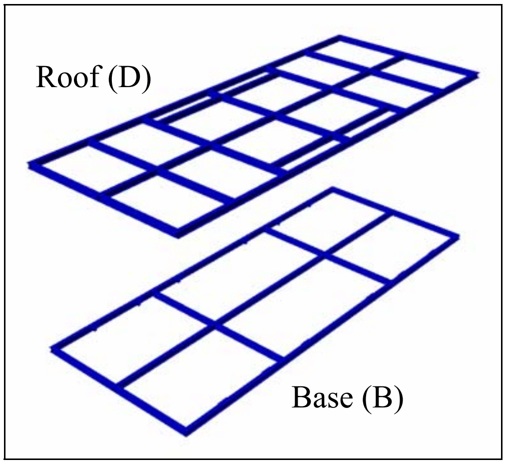


Figure 4.2.4: Frame Structure

4.3. Event Model

The following is an event model for the deployment and the dismantling of the *ASPALT*. It is assumed that this event model will utilize the procedures integrated into underway replenishment; therefore, details regarding the beginning stages of underway replenishment will not be incorporated into the following event model.

Event Model of *ASPALT* (Assembly)

Step	Procedure	Time (minutes)
1	The *ASPALT* rests in front of the delivery vessel's kingpost. A highline is run though the wire housing, under the highline pulleys.	3
2	The delivery vessel sends over a shot line with a messenger line attached that is pulled until the highline is aboard.	5
3	The highline is secured to the receiving vessel's kingpost, and is tensioned though the use of a ram tensioner aboard the delivery vessel.	5
4	The outhaul line placed through the wire housing, under the outhaul pulley.	3
5	A shot line is sent across with a messenger line that is pulled until the outhaul line is aboard the receiving ship.	5
6	The receiving vessel places the outhaul line through an outhaul padeye and then sends the remainder line back to the delivery vessel as the inhaul line.	5
7	Once the inhaul line is received, it is placed through the inhaul grips within the wire housing and secured to the ram tensioner system on the delivery vessel.	5

8	All connections are checked as a safety precaution on both vessels. Once completed a signal is sent from the delivery vessel to the receiving vessel indicating preparation has been completed. The receiving vessel will notify the delivery vessel that it has received their signal and will signal back when they are ready.	5
9	The wire housing, frame, and top will rise as the kingpost rises until both 4 ft sections are in line with each other and the tubes completely inflated.	3
10	The mesh on each side of the *ASPALT* is secured to the roof and base as well as inspected for safety. The gates are also attached to the posts on each end.	3
11	A final inspection of the entire *ASPALT* is conducted to insure safe passage between ships.	5
12	20 personnel enter the *ASPALT* side by side and secure themselves within it by gripping the mesh and closing the gates.	5
	Total assembly time:	52

To disassemble the system:

Event Model of *ASPALT* (Disassembly)

Step	Procedure	Time (minutes)
1	Place *ASPALT* over deck of delivery vessel. Deflate the tubes attached to the bottom plate and lower the *ASPALT* structure to the deck.	2
2	Remove the mesh and unsnap the posts so that they are able to move by its hinges.	6
3	Lower the kingpost until the *ASPALT* is completely folded, as seen in figure 4.2.2.	3
4	Remove inhaul line from within ram tensioner system and wire housing.	5
5	Signal the receiving vessel once this has been completed, and begin to pull the outhaul line back to the delivery vessel.	5
6	The receiving vessel disconnects the highline for their kingpost and the delivery vessel pulls the highline aboard.	5
7	The highline is removed from the wire housing and the *ASPALT* is placed back to storage.	3
	Total disassembly time:	39

Again this event model is only an indicative procedure, and an estimate of the type of procedure needed for the *ASPALT* system to work.

4.4. Emergency Breakaway / Failure Scenario

The emergency breakaway procedure will follow the guidelines as mandated in the underway replenishment procedure. If such a maneuver is necessary while the *ASPALT* is in transit, no lines will be removed in any manner from either vessel (Surface Warfare Officers School Command Connected Replenishment). Mainly the tension in the lines strung across the vessels will be reduced as to allow for better mobility for each vessel. In this case the *ASPALT* will have a high risk of falling in the seas. Depending on how fast the tensions in the lines are reduced will determine the severity of the fall. Most likely the *ASPALT* will fall with some force, but the structure should hold and the inflatable tubes will provide buoyancy keeping the occupants afloat. Once emergency breakaway procedures have been conducted, the lines are tensioned again and the *ASPALT* continues to move to the next vessel.

In the event of a catastrophic failure occurring in which the highline becomes completely disconnected from the receiving ship, the *ASPALT* will fall quickly into the sea possibly injuring and killing the occupants. When this occurs, standard procedure for retrieval of personnel in the sea will be preformed.

4.5. Future Direction

Due to the time constraint of this project, several details for the *ASPALT* have been unexplored. One such detail is a device required to stabilize the *ASPALT* while in transit above rough seas built between the rigging and the wire housing. That device would ensure stability for the occupants inside and possible cargo as well as protecting it from falling into the sea.

Another area for further development would be researching the realm of composites. The only composite mentioned previously was high density carbon fiber, a typically strong composite, could be used, but there are other alternatives the Navy currently uses for various applications in ship construction. Currently the Navy uses a composite for overhead walkways on several aircraft carriers.

In order to equip the *ASPALT* with specific type of inflatable, further research is required. There are many different types of inflatables commercially of various shapes, materials, and sizes. An ideal inflatable would be one whose material is very durable and rugged while capable at keeping the *ASPALT* afloat if it were to fall into the sea. The material needs to be light enough for compact storage under the *ASPALT*. It would have to be self-inflating or inflate very fast using a pump.

Currently there is no procedure for attaching the mesh to the top and bottom of the *ASPALT* as well as the kind of material best suited for this application. The type of material required must not wear out very easily and must support the force exerted on it by the structure and the occupants inside. With the necessary developments and research this system is a viable, relatively lightweight, safe, and compact alternative for at sea personnel transport.

5. *PTS* - Design Description

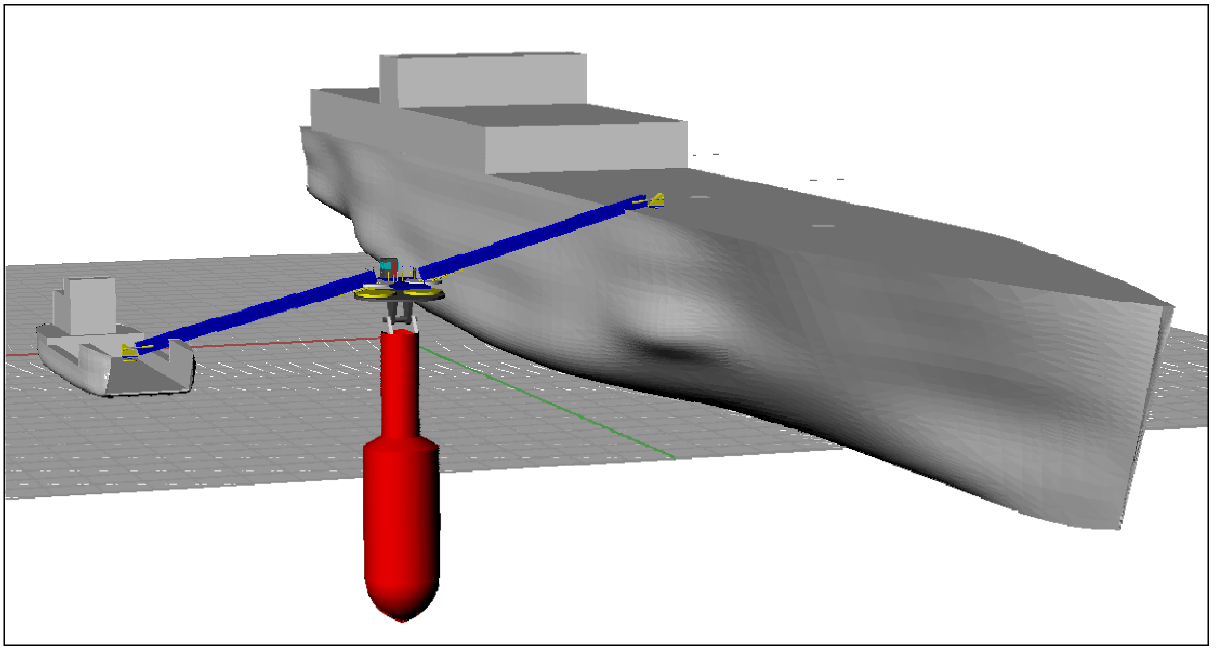


Figure 5.0.1: LCU *PTS* LMSR Arrangement

The *PTS* or Personnel Transfer Spar, will act as an rigid intermediary vessel between transferring vessels for the use of at sea personnel transfer. The arrangement of the system would be two sea basing vessels, station keeping relative to each other, with the spar buoy also maintaining relative position to allow for personnel to safely and swiftly move from one ship to another. Ideally, the spar will have two or more, self deploying bridges that will be capable of attaching to the sides or decks of the adjacent vessels. This system could be automated or remote controlled to reduce risk of injury and the need for additional manpower.

Item	Measurement
Length of System	157 feet
Width of System	40 feet
Diameter of Spar	32 feet
Weight of total system unballasted	1215 tons
Weight of total system ballasted	2862 tons
Power supply	27.5 kW 4-cylinder diesel generator
Operating time	30 days
Catamaran/Tug deck space	40 feet
Catamaran/Tug payload	50 tons
Throughput rate	300 men/hour

Table 5.0.1: Basic *PTS* Specifications

5.1. Evolution of Concept

Figure 5.1.1: Oil Spar

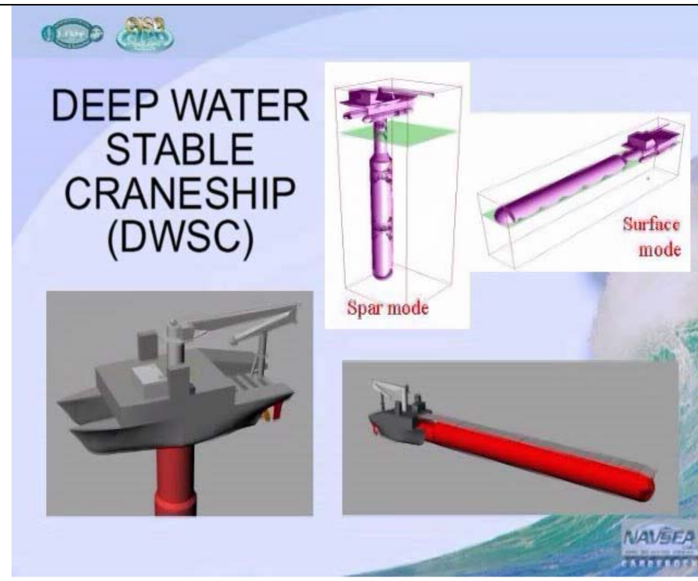


Figure 5.1.2: Deep Water Stable Craneship

The *PTS* design was inspired by the spars found in the oil industry see Figure 5.1.1. These spars support large payloads and perform well in high sea states. The size of the spar depends directly on the payload's weight and height above the average water surface. Another design that aided in the development of the *PTS* was the deep water stable crane ship seen in Figure 5.1.2, (Selfridge). The crane ship is a rapidly deployable, independent spar vessel that is ferried into place by a large catamaran. This vessel can support large loads while maintaining a slow role period in high sea states. The *PTS* is intended to perform in a very similar manner except the payload will be considerably smaller. The primary concern is the safe transportation of marines and their associated gear from one vessel to another. The system needs to be robust enough to accommodate at least one marine in transit. The marine and gear is assumed to weigh no more than 315 lbs according to the STO-PAC report, this weight was used for the development of this study. The *PTS* requires a bridge to span the distance between the spar and the transferring vessels. It is assumed that the bridge needs to be at least 100 feet and will be rigid allowing the system to be modeled by a beam that is pin supported at either end.

In order to carry one marine with a safety factor of 3 the bridge structure will need to resist a shear force of 475 lbs and an internal moment of 24000 lb ft. The ladders used on emergency rescue vehicles matched the needs accordingly. The hydraulically driven ladders are capable of reaching 100 feet, supporting 1000 lbs at the tip of the ladder, and sustaining a 60000 gal/hr hose firing at any angle. The ladders are capable of supporting this weight in a range of -5° to 85° from the horizontal plane and are extendable to accommodate any distance between 40 and 100 feet. This system is run from a 10 kW hydraulic pump that is powered from the vehicles diesel engine, and all systems associated with the ladder are resistant to water damage. To properly accommodate the needs of personnel transfer the design of the ladders would have to be modified but the rescue ladder provides a good base for estimating what power requirements and performance specifications could be expected of a similar system.

To run one ladder requires a 10kW hydraulic pump, it is assumed a 22 kW hydraulic pump would be adequate for two. The hydraulic pump would be powered by a small diesel generator. The hand rails of the ladders would have to be extended to accommodate a standing marine instead of a climbing fire fighter. Finally, the rungs of the ladder would have to be changed to flooring, increasing the overall weight of the ladder. The bridges would also retract to their shortest length and could be swiveled onto the deck of the spar for storage much the same way the ladders are stored on the emergency vehicles.

The system is intended to be autonomous but in case of emergency or system failure it would be beneficial to have an onboard method of controlling the *PTS*. A small deck house, about twice the size of a phone booth would be adequate to house the proper equipment and shield the operator from the elements. The spar is not intended to maintain personnel presence, so provisions and life support, beyond emergency equipment, is not required.

The primary power supply aboard the *PTS* would be the small 25kW diesel generator that burns approximately 2.1 gal/hr or 50 gallons of diesel fuel a day. Operating at full load, the generator could run for 30 days on 1500 gallons of fuel. Considering the small size and weight of the generators the vessel could easily be outfitted with two for redundancy and backup power. Fuel consumption can affect the performance of a spar ship by raising the vessel out of the water and altering the Center of Gravity (CG) as fuel is burned. A variable ballasting bladder is necessary to account for the loss in weight during operation. This will be later discussed when the size of the spar is determined.

Considering the motions of the transferring vessels the two adjacent bridges would need to compensate for roll of the vessels by extending and retracting accordingly. Also if the vessels failed to maintain relative position to each other or the buoy, the swivel base of the bridges would compensate for small amounts of deviation. However, the pitch motion of the vessels would produce a torque in the perpendicular bridge causing the system to fail. A compensator would have to be designed to allow the extendable bridges to roll at small angles to match the pitch motion of the transferring vessels.

A common joystick was modeled for the base of the ladder, but to allow for more dynamic response, a universal joint was designed in its place. This joint would allow for free movement of the ladder in any direction. The next progression for the design of the base was to consider how to make it safe for marines to get on and off the ladders. The base swivels and rolls while the ladder itself can change angle relative to the deck of the spar. This irregularity between the deck and the ladder could create a hazard for marines. Stepping from the bridge that is moving on three axis to a stationary deck, at sea, in sea state 4, could produce a similar anxiety experienced when stepping from an escalator to the ground. To make the transition more reasonable, a small circular deck that follows the motions of the bridge could be installed as a base, as seen in Figure 5.1.3. This deck would be circular to allow it to swivel with the bridge as it turned. To further reduce the relative motions, the flooring of the bridge would end at the fulcrum point, shown in Figure 5.1.3, where there is the least amount of relative motion. A rubber skirt could be placed between the base of the bridge and the deck as well to reduce the risk of injury due to the gap.

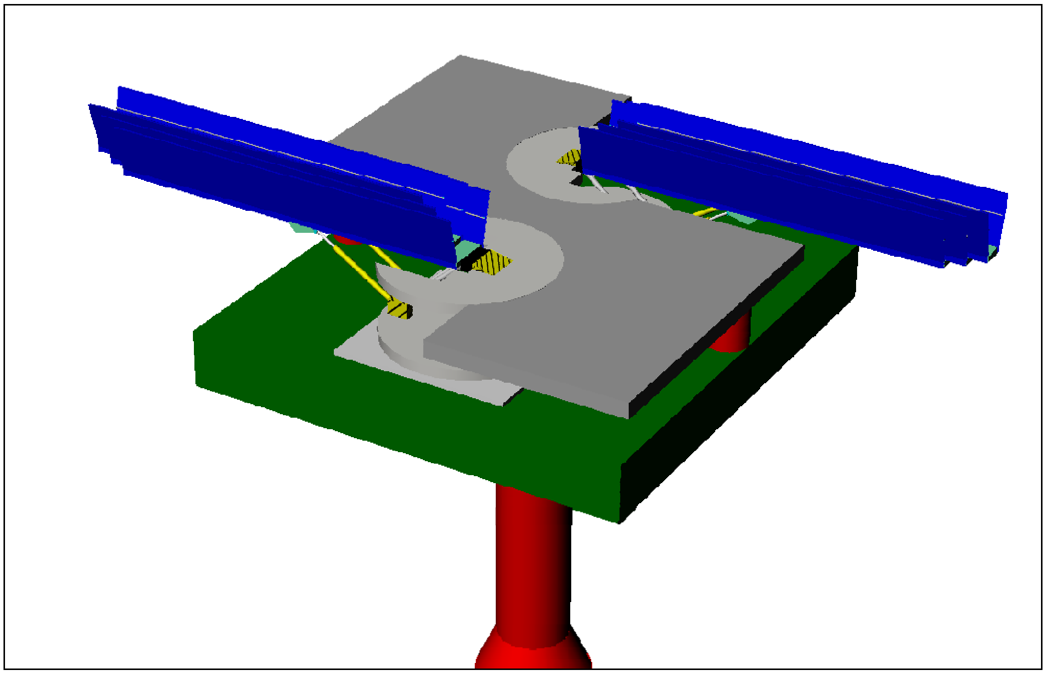


Figure 5.1.3: Stored Spar

If the extended ends of the bridges sat on the decks of the adjacent ships they would shift and slide making it a very dangerous for personnel. The bridge will need to rest flatly on the deck to be properly secured. As seen in Figure 5.1.4, some rescue ladders are equipped with an end basket that maintains a horizontal configuration despite the angle of the main ladder. A similar end arrangement would provide a secure platform for securing the bridge flatly to the decks of the transferring vessels. The hinged end would allow the bridge to sustain what ever angle necessary for transfer. Shocks or oil filled dampeners would be mounted to the hinged section to prevent fast articulation that could be hazardous to personnel.

Figure 5.1.4: Rescue ladder vs. *PTS* ladder

In theory, if the base of the bridge could move freely to match the motion of the transferring ships it would prevent damage to the vessel. However, it would be less hazardous for personnel if the bridges remained stationary and all motion compensation occurred at the connection between the bridge and the deck of the transferring vessel. The marines and their gear would have a better chance of successful transfer if the bridge moved as little as possible. The universal joint at the base of the bridge was scrapped and replaced with a vacuum mooring system at the end of the bridge that is capable of accomplishing the same job.

The New Zealand based company Mooring Systems Limited has a handful of operational vacuum mooring systems; the most notable was installed in 1999 and claims over 10,000 successful dockings. Currently vacuum mooring is exclusively used for securing ships at dock but the ability to moor ships together at sea using the same vacuum system is plausible. MSL has already anticipated the necessity for such a system and has designed a specific unit for such tasks the next step would be implementation.

The vacuum head has the ability to swivel on a socket joint and can move independently on two rails in the horizontal plane. The mooring systems used for 230 – 825 foot ships require up to 4 mooring units each maintaining a 40 ton load. These units are roughly twice the size required for the *PTS*, a rough comparison in shapes can be seen in Figure 5.1.5.

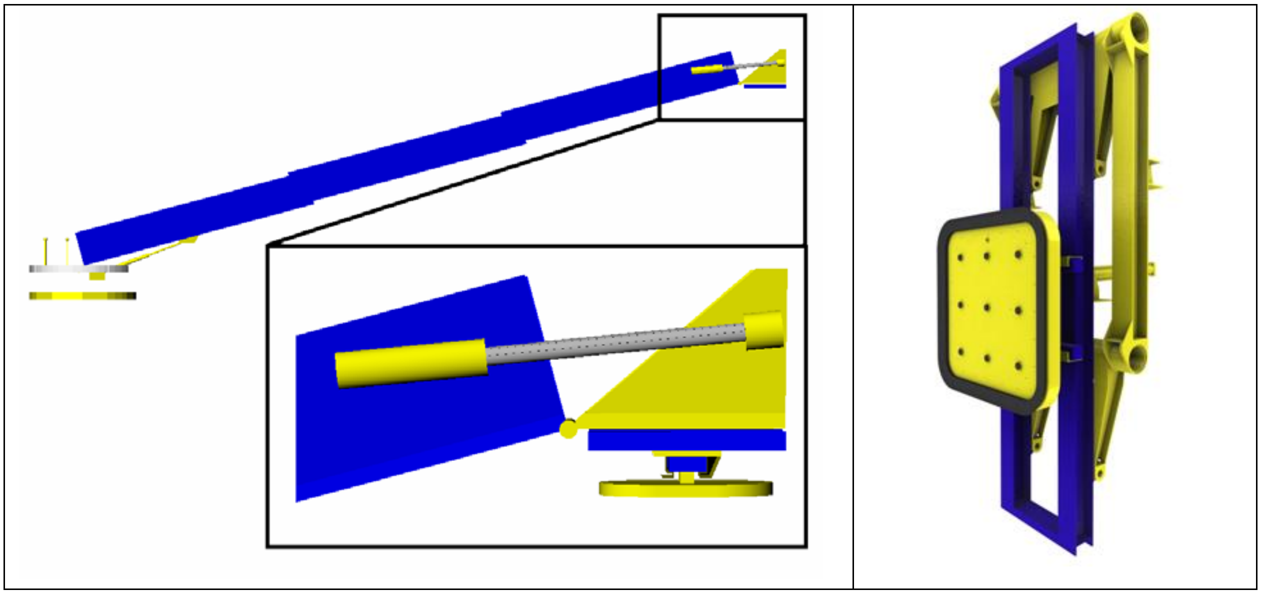


Figure 5.1.5: Vacuum Mooring

The load capacity of the mooring panels on the *PTS* would have to be lowered to allow for safe breakaway in severe conditions. The bridges on the *PTS* are rigid and are designed to support the weight of the extended bridge and any personnel in transit, so it would be preferred to break away easily than to maintain contact and destroy the *PTS* or potentially harm personnel.

Using the components chosen a spar size and weight can be determined. An estimated payload weight of 50 tons was used to determine the first iteration of spar design. Currently research is being conducted at NSWC Carderock to design a range of spar ships similar in magnitude to the *PT*S, this research data was used to estimate the parameters of the spar required for this system. Assumptions made while using this data are that the payload will be 37.7 feet off of the sea surface and the truncated connection between sections of the spar will have wall angles of 30º relative to the horizontal plane. The initial iteration produced a spar that was 295 feet long and weighed 1600 tons. The data shows a trend for spars of any length and a weight between 1000 tons and 3500 tons that an ideal spar diameter is 33 feet or 10 meters as seen in Figure 5.1.6.

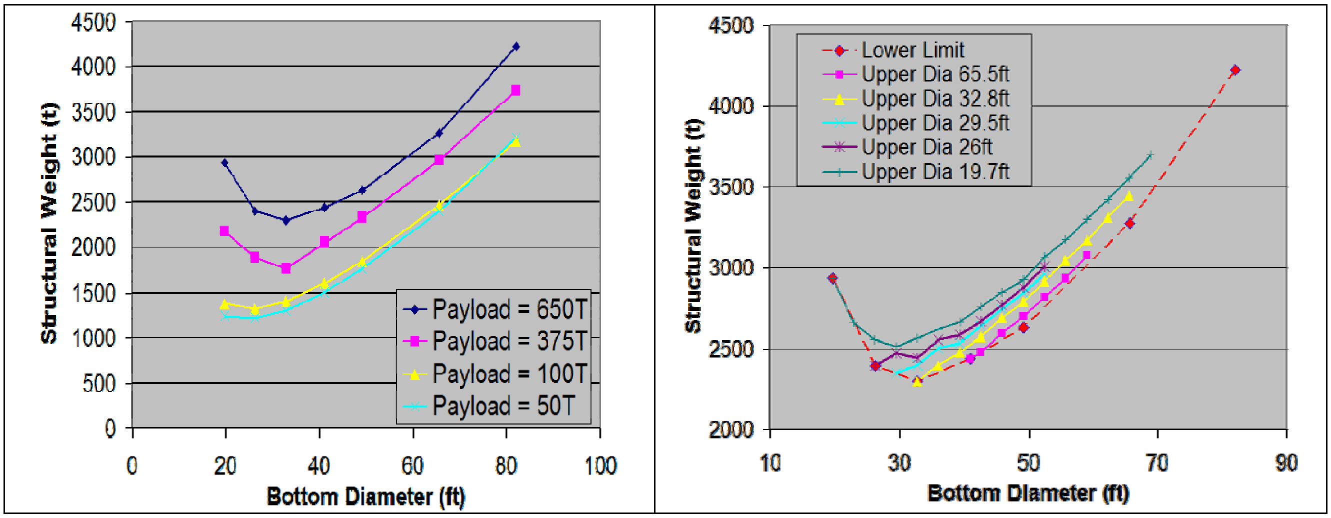


Figure 5.1.6: Structural Weight vs. Bottom Diameter

The data also shows that a spar with a payload between 50 and 100 tons does not vary significantly for required submerged depth this can be seen in Figure 5.1.7. For the second iteration of the spar design a 33 foot diameter was factored in and a final weight of 1215 tons, length of 134 feet, and submerged depth of 104 feet was determined.

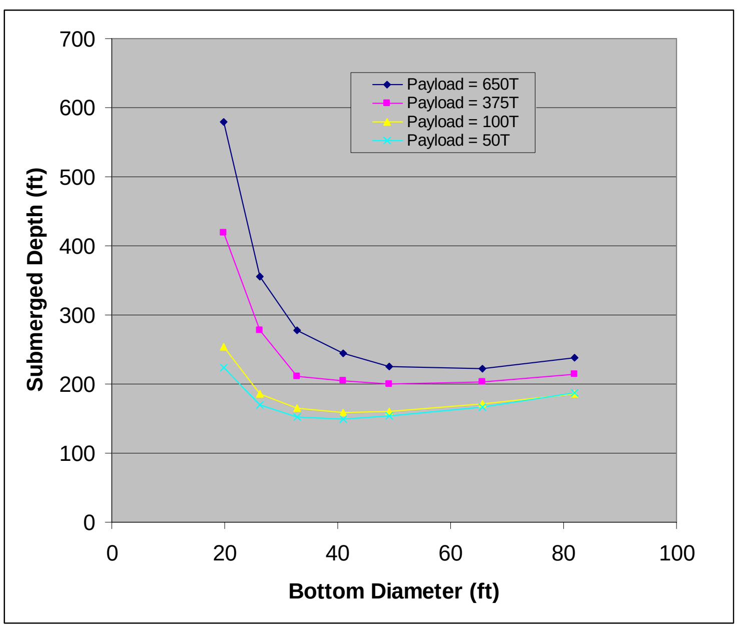


Figure 5.1.7: Submerged Depth vs. Bottom Diameter

Having found the size and weight of the spar an appropriate fuel tank can be chosen for the *PTS*. As mentioned earlier a 1500 gallon tank will allow the system to operate for 30 days at full load. Assuming DFM, diesel fuel marine, has a density of 827kg/m^3, 1500 gallons would weigh 5.18 tons. With a diameter of 33 feet, it would require 27 tons to increase the draft of the *PTS* by 1 foot. The difference in a full fuel tank and an empty tank translates to 3 inches of change in draft. Because of the nominal change in draft a variable ballasting tank was deemed unnecessary.

Because of its size the *PTS* will not fit on the deck of a cargo ship and will be too heavy to maneuver using a crane. Instead, the *PTS* will need to be ferried into the sea base with a heavy lift ship. In order to deploy a *PTS* from a heavy lift ship it would have to be self propelled or dragged away from the heavy lift ship in the horizontal position. The catamaran required to move this size spar would be roughly 75 feet long and weigh around 370 tons. A permanently attached catamaran would add undesirable payload weight to the *PTS* resulting in the need for a larger spar. A tug boat could drag the *PTS* out of the way of the heavy lift ship, there it could ballast and resume operations autonomously. Another design alternative would be a catamaran that pushes the spar into place then detaches from the system thereby not adding any weight to the operating *PTS*. For any of these deployment methods the *PTS* will be pushed or dragged through the water, to prevent damage to the sensitive systems such as generators or the deck housing, components will need to be stored above the waterline. To accomplish this, the deck and the spar of the *PTS* would be connected via a large hinge that would allow the spar to shift 90º to become parallel with the water line while in the stored or transfer configuration as seen in Figure 5.1.8.

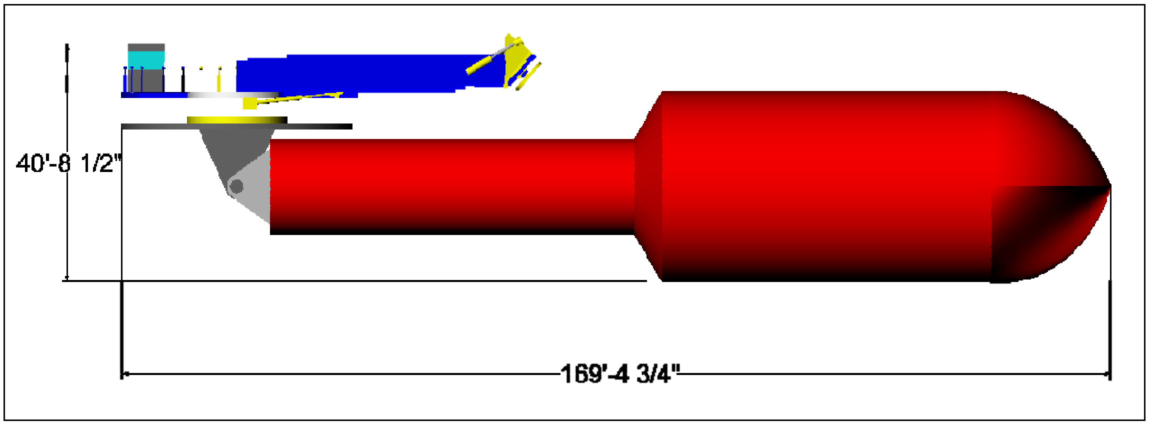


Figure 5.1.8: Stored *PTS*

5.2. *Detailed Description*

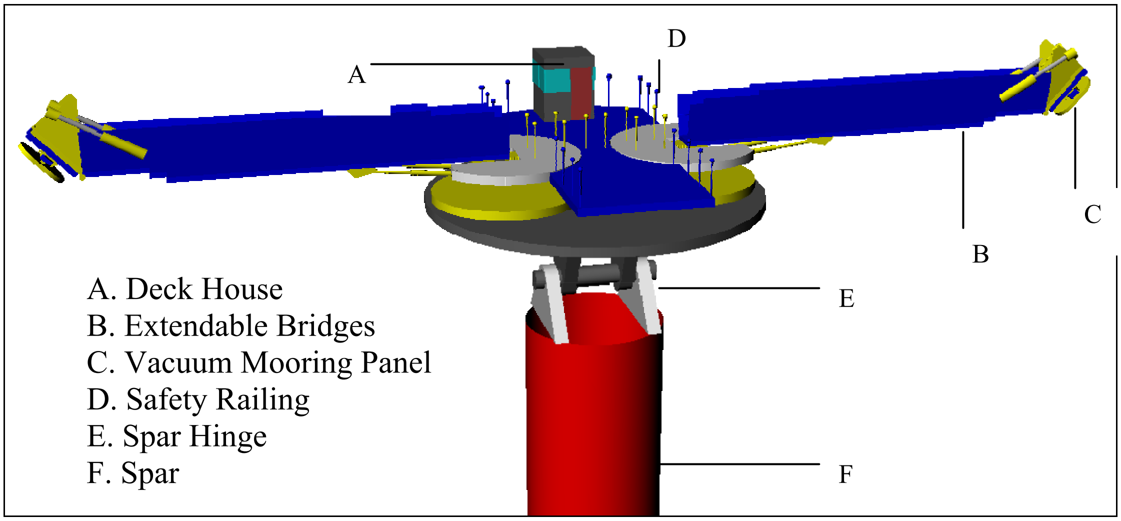


Figure 5.2.1: *PTS* Upper Deck

Item	Weight	VCG
Bridges and Hydraulic hardware	20,000 lbs each	149.28 ft
Diesel Generator	1,030 lbs each	144.36 ft
Fuel	5.1755 tons = 10351 lbs	98.43 ft
Hydraulic Motor and Pump	274 lbs each	143.5 ft
Vacuum Mooring	300 lbs each	148.36 ft
Vacuum Pumps	50 lbs each	140.75 ft
Deck Structure	15.5 tons = 31000 lbs	144.30 ft
Spar structure	1200 tons = 2,400,000 lbs	80.315 ft
Ballast weight	1607 tons = 3,214,000 lbs	39.44 ft
Total	About 2860 tons	About 58 ft

Table 5.2.1: Component Weights and VCG

The *PTS* will not have independent far ranging capabilities and as a result would be exclusively associated with the sea base. Any ships requiring high volume personnel transfer would be required to move into the sea base to conduct operations. However, having a system that is independent of the ships it services would allow for much greater diversity and a greater over all capability. Because the *PTS* requires no deck space from the transferring vessels and is capable of reaching deck heights ranging from 0 to 70+ feet off the ocean surface it would be indiscriminant of what vessel it serviced.

Because of its lack of range the spar system would have to be ferried into place, on the deck of a heavy lift ship, along side other sea basing equipment. The *PTS* would have a slow initial set up time but once deployed the spar could be a relatively easy and quick system to implement. With dynamic positioning (DP) technology being so aggressively researched it is not unrealistic to assume that this system could be completely automated and require no ship to ship tethering

The bridges (B) of the *PTS* will be extendable from 45ft to 100ft long each, creating a 221ft expanse. The bridges will be capable of reaching from an LMSR, light ship deck height 70 feet to a LCU, deck height 6 feet at an angle of 17 degrees (Delucia). At half extension, the angle will shift to 32º. The bridges have a vertical range between positive 45º and negative 45º to compensate for role motions of the vessels in an open seaway. The limiting factor to what angles the *PTS* can operate is the marines' ability to climb the bridges with gear.

The primary power supply for all upper deck equipment of the *PTS* would be two small diesel generators. The 27kW generator would operate the 25kW hydraulic pumps and the all the miscellaneous electronics aboard. A *Cummins* 4 cylinder marine diesel generator that produces 38 hp with an output of 27.5 kW would fit the requirements perfectly. Operating at full load the generator runs at 1800 rpm and burns 2.1 gal/hr, about 50 gallons of diesel fuel a day. A 1500 gallon tank would run the *PTS* for approximately 30 days if operated at full load continuously. The differential height of the *PTS* when the fuel tank is full vs. empty is 3 inches, so a compensator for weight loss is unnecessary.

The *PTS* will secure to the transferring vessels via a vacuum mooring system (C). The vacuum panel will need to be about 2.5 feet wide by 5.5 feet long. This will be a smaller and lighter than mooring system than currently exists. The lighter mooring panel, estimated to be 300 lbs, will not be a significant burden for the bridges. To further reduce the tip weight, the vacuum pumps will be stored on the deck of the ship and hosing will be run to the vacuum panels.

The *PTS* is intended to be autonomous or remotely controlled however the *PTS* also has the ability to be operated manually through controls in the deckhouse (A). It is necessary to have back up control during transfer and in case of emergency. The deck house will also be storage for any emergency equipment.

Railing (D) will be installed along the edges of the upper platform for safety and railings will also be placed between bridges to help personnel make the transition across the deck easily and safely.

The *PTS* will be self deployed via catamaran or towed into place using a tug. The spar (F) and the decking will require a hinged connection (E) to ensure the safety of sensitive components during deployment, recovery, and storage of the *PTS*.

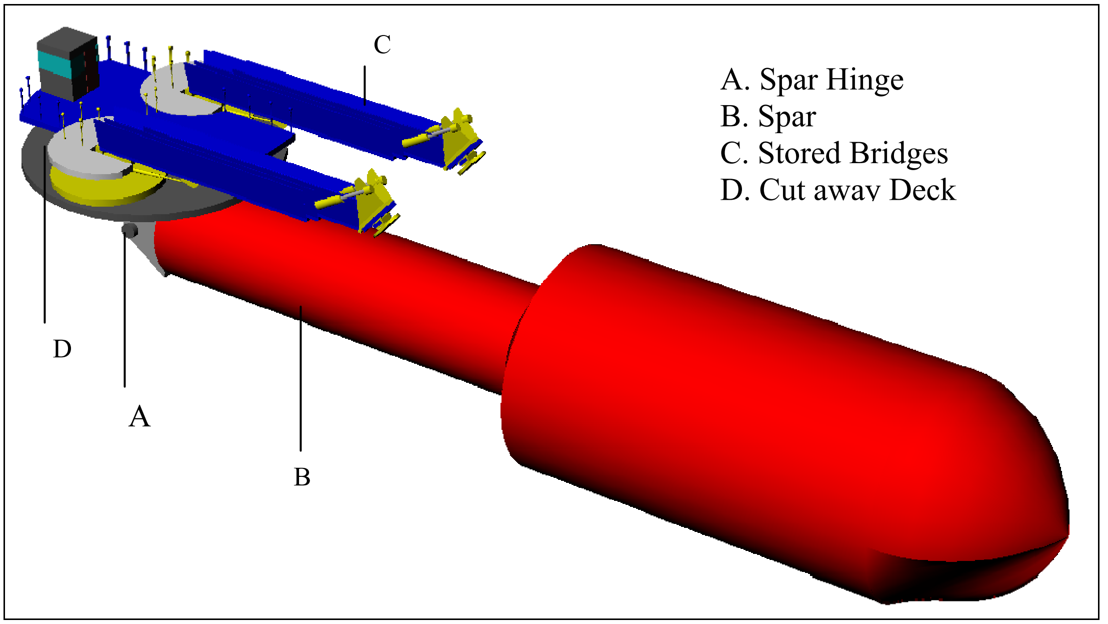


Figure 5.2.2: Stored Configuration *PTS*

The advantage of an intermediary vessel is that it is not dependent on other ships to maintain stability. The *PTS* is a standalone vessel, and will not sink or fall into the ocean if the connection to the transferring vessels is severed. Furthermore, the bridges of the *PTS* are designed to act as cantilever beams and are capable of supporting the weight of multiple marines without the tip support of adjacent ships. The connection from vessel to vessel is secured with vacuum mooring, no lines or bolts hold the *PTS* to the adjacent vessels. In stead of destructively disconnecting the system in an emergency the vacuum pressure could be adjusted to ensure the bridges automatically break free when conditions become increasingly severe. This breakaway capability would prevent the ships and the spar from being damaged and would minimize the hazard to personnel in high sea states. If the spar ship is disconnected and there are personnel still on board there is manual control located in the deck house along with some emergency equipment.

5.3. Event Model

Event Model of *PTS* (Initial deployment)

Step	Procedure	Time (minutes)
1	The *PTS* is ferried into the sea base from a propositioned supply port.	NA
2	The heavy lift ship ballasts down to allow the *PTS* to deploy.	400-600
3	The *PTS* is driven into place by the catamaran/tug.	20
4	The spar ballasts down and raises the *PTS* into transferring height.	300
	Total assembly time:	720-920

Event Model of *PTS* (Connect)

Step	Procedure	Time (minutes)
1	*PTS* and ships move to formation for personnel transfer.	NA
2	The *PTS* extends bridges and places them on the decks of the adjacent vessels.	5-10
3	The vacuum mooring secures the bridges to the decking.	1
4	An operator boards the *PTS* and mans the manual controls in case of emergency.	5
	Total assembly time:	16

Event Model of *PTS* (Disconnect)

Step	Procedure	Time (minutes)
1	After personnel transfer is complete the operator of the *PTS* also leaves.	5
2	The vacuum mooring releases from the decks.	1
3	The bridges retract and fold into storage positions.	5
	Total assembly time:	11

The initial deployment and final storage of the *PTS* only occur when the sea base is initiated and broken down. Once the *PTS* is deployed it only takes minuets for connection to occur and personnel to begin transfer between vessels. The disconnect procedure is equally swift, making it very efficient system for the transferring vessels, but time consuming in the end for the *PTS* and associated logistic ships.

5.4. Emergency Breakaway / Failure Scenario

In the case of an emergency breakaway scenario, the vacuum mooring panels could quickly dislocate from the adjacent vessels allowing the transferring ships to respond to the situation free of tethering. If the spar ship is disconnected and personnel are still on board there is a manual control located in the deck house along with emergency equipment.

If the system dislocates during high sea states, the transferring vessels may roll outward with the wave action, then roll back to slam into the extended bridges of the *PTS*. The level of damage the system would sustain is unpredictable but more importantly, the personnel on the extended bridges would be in danger

The *PTS* is a standalone vessel, and has all the associated problems, fire hazards, maintenance, corrosion, upkeep, etc. The vessel could become caught in high seas, the ballast system may fail catastrophically, or the ship may be attacked resulting in the sinking of the *PTS*.

At this point the Navy would determine the feasibility of retrieving the spar or building another. However, in the event personnel are onboard the vessel during an emergency, the *PTS* is large enough to comfortably contain an inflatable life raft.

5.5. Future Direction

There are many details that require further development before it is determined whether or not the *PTS* would be a reasonable solution for at sea personnel transfer. Dynamic positioning is one crucial element for this design to operate as intended. It is not unrealistic to assume the integration of this technology is achievable in the next 5 to 10 years knowing the DP software required for a system like the *PTS* is currently being researched and tested at several universities.

The spar design for the *PTS* is still very preliminary. Software that would produce simulations of response need to be run and further iterations of size and weight estimations need to be conducted before a model can be constructed for testing. Spar technology could dramatically change the capabilities and methods of the Sea Base concept. Currently the spar is being researched for heavy lift capabilities for the purpose of transferring cargo between vessels at sea. This technology could easily be adapted to meet the requirements of personnel transfer in the future and proves there is an interest in similar systems. Perhaps it will be found that larger spar ships could be used for more than one application and this method of personnel transfer would simply be added to the larger vessel as a secondary function.

Spar ships could become a defining feature of the Sea Base in the future. Spar ships could be used for not only cargo and personnel transfer but also for defense if outfitted with a SLAMRAAM unit. They could also be used for logistics and communications if equipped with radar and appropriate communication towers. As discussed earlier, research has shown that spar size differs by a nominal amount for payload weights between the 20 and 100 tons. A universal sized spar buoy could be designed that would accommodate this range of payload requirements and a modular system could be adapted similar to the littoral surface combat ships. The top section of the buoy, whether it is ladders for personnel transfer or rockets for defense, could be removable and stored separately. This would allow the sea base to maintain a small fleet of universal buoys in queue but change the modules to match the requirements of the mission in mind.

Another large design variation facing the spar is deployment method. A few options are plausible; the spar could have a permanently attached catamaran giving the vessel the ability to be completely self-deploying. If multiple spars populate the sea base it would be redundant and inefficient for each spar to have its own catamaran. A catamaran could be designed to deploy a spar and then detach from the system and return to deploy multiple spars. Alternatively, the spar vessels could also be designed to be towed into position in a train like configuration with a tug boat. The largest disadvantage to this is of course the added weight associated with the catamaran. There are many avenues of design left for future research of the *PTS* system.

6. Conclusions

6.1. Conclusions

The mission of this innovation cell was successful in creating concepts for transferring personnel at sea. Within this report are three unique solutions to only one problem. Having three solutions allows the Navy to have more options in selecting a solution that fits their sea basing agenda. The *C-CaSBr* is a novel design that utilizes lightweight material in its construction and can be implemented easily onto the existing fleet, but works best when then the angle of the *C-CaSBr* is not a small relative to two vessels. The *ASPALT* utilizes the current method and technology of underway replenishment between ships underway. However, the components of this concept are not new, but require vessels to be equipped with means of conducting underway replenishment. The *PTS* has the ability to be fully autonomous within the intra-theater setting of the sea base, but further research and development of systems are needed for the *PTS* to be fully autonomous due to its unique design. Every one of these designs has improved the throughput rate and reduced the hazards of today's systems. The *ASPALT* and the *C-CaSBr* are designed for underway replenishment similar to today's UNREP, where the *PTS* is best suited for a stationary sea base. Even though each design is feasible, more research must be conducted in order to determine whether or not each design can sustain operation in sea state 4 or higher as well as develop new criteria to condense these concepts into one that would best fit the Navy of today and of the future.

6.2. Experience

In regards to our experience at the Center for Innovation in Ship Design many lessons have been learned. Time management and trusting in the ability of each of our teammates were major contributors to the success of this team. Creating a schedule divided our time allowing it to be used efficiently, and trusting the ability of each teammate allowed sharing of the workload by delegating each team member equally challenging and complex tasks. Working with computer technology such as Rhinoceros® and Bryce® allowed this team to better visualize the appearance of each design as well as demonstrate its motion. This team also was able to learn from experienced individuals and utilize their knowledge and expertise as a guide to further develop our designs. Lastly designing something unique that one day may impact how people will move from ship to ship.

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Appendix A: Weight Charts

	Safety	Functionality at Sea State 4	Transfer Rate	Retro-fit	Rapid and automated	Transport with packs	Protection from Environment	Storage	Weight/ Size	Simplicity	Maintenance	Power Required	Training	Total	%
Safety		1	1	1	1	1	1	1	1	1	1	1	1	26	14.29
Functionality at Sea State 4	-1		-1	1	1	1	1	1	1	1	1	1	1	22	12.09
Transfer Rate	-1	1		0	1	1	1	1	1	1	1	1	1	23	12.64
Retro-fit	-1	-1	0		-1	-1	1	0	-1	-1	1	1	1	12	6.59
Rapid and automated	-1	-1	-1	1		-1	1	0	1	-1	-1	1	1	13	7.14
Transport with packs	-1	-1	-1	1	1		-1	1	1	-1	-1	1	1	14	7.69
Protection from Environment	-1	-1	-1	-1	-1	1		1	-1	-1	1	1	1	12	6.59
Storage	-1	-1	-1	0	0	-1	-1		0	1	-1	-1	1	9	4.95
Weight/ Size	-1	-1	-1	1	-1	-1	1	0		-1	-1	1	1	11	6.04
Complexity	-1	-1	-1	1	1	1	1	-1	1		-1	1	1	16	8.79
Maintenance	-1	-1	-1	-1	1	1	-1	1	1	1		1	1	16	8.79
Power Required	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	-1		1	6	3.30
Training	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1		2	1.10
														182	100

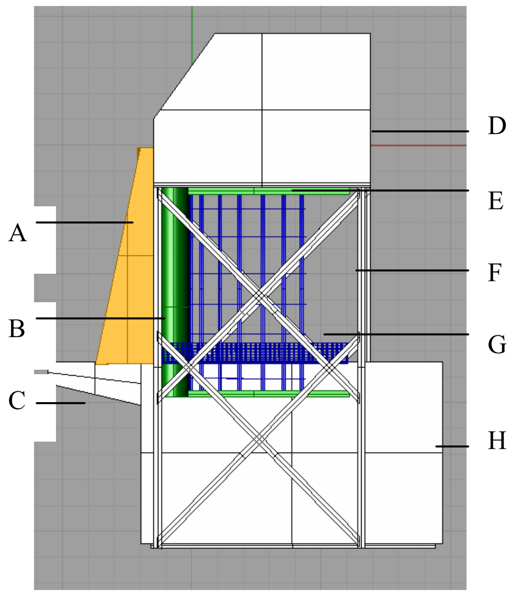
Table A.A.1: Requirement Weight Chart

Appendix B: Acronym List

ASPALT	At Sea Personnel Aerial Lift Transfer
CISD	Center for Innovation in Ship Design
C-CaSBr	Covered Cable Suspension Bridge
CG	Center of Gravity
CONREP	Connected Replenishment
DFM	Diesel Fuel Marine
DP	Dynamic Positioning
JHSV	Joint High Speed Vessel
LCAC	Landing Craft Air Cushion
LCU	Landing Craft Utility
LO/LO	Lift on/Lift off
LMSR	Large, Medium Speed, Roll on/Roll off
MLP	Mobil Landing Platform
MPF(F)	Maritime Propositioning Force (Future)
MSL	Mooring Systems Limited
NAVSEA	Naval Sea System Command
NSFS	Naval Surface Fire Support
NSWC	Naval Surface Warfare Center
ONR	Office of Naval Research
PTS	Personnel Transfer Spar
SLAMRAAM	Surface Launch Advance Medium Range Air to Air Missile
STREAM	Standard Tensioned Replenishment Alongside Method
SWATH	Small water plane area, twin hull
TEU	Twenty foot equivalent unit
TPF	Ton per foot
VCG	Vertical Center of Gravity
UNREP	Underway Replenishment

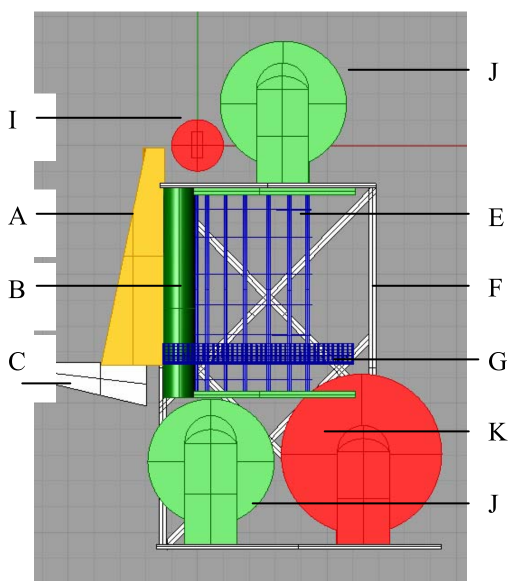
Table A.B.1: Acronym List

Appendix C: Further Detailed Diagrams of *C-CaSBr*



A. Receiving Frame
B. Canvas Rollers
C. Lower Casing opening
D. Upper Compartment
E. Vertical Safety Netting
F. Structure Beams
G. Horizontal Safety Netting
H. Lower Compartment

Figure A.C.1: Right Side View: *C-CaSBr*



A. Receiving Frame
B. Canvas Rollers
C. Lower Compartment Opening
E. Vertical Safety Netting
F. Structure Beams
G. Horizontal Safety Netting
I. Canvas Reel
J. Cable Reel
K. Flooring Reel

Figure A.C.2: Right Side View, Casing Removed: *C-CaSBr*

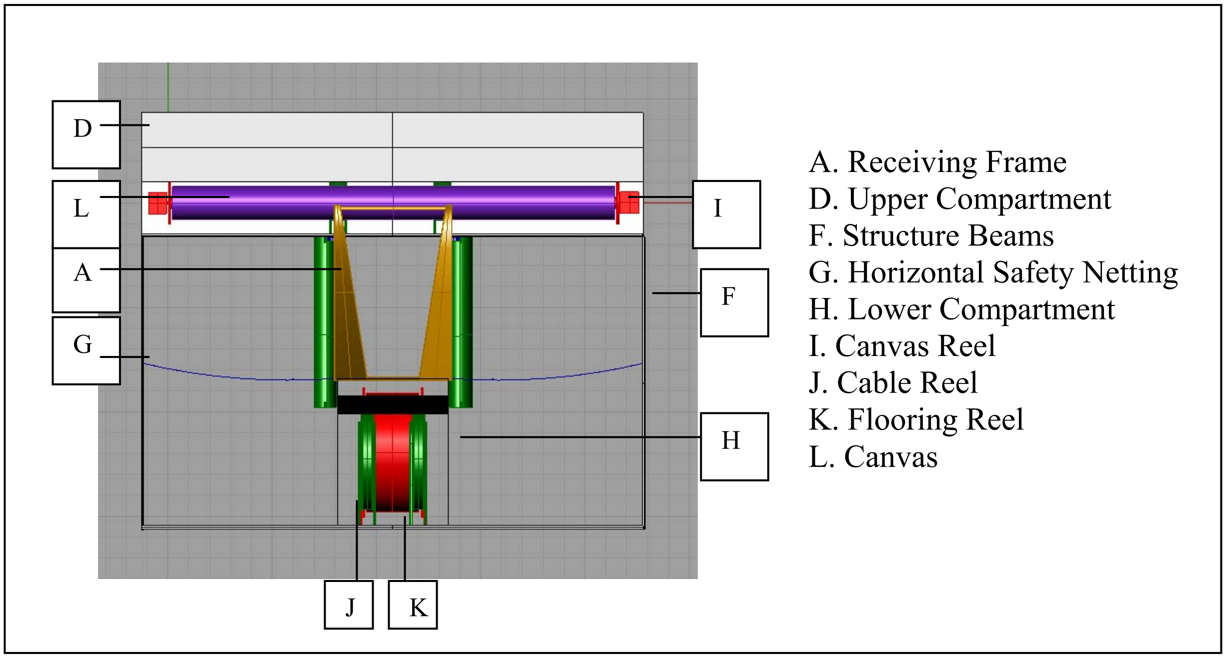


Figure A.C.3: Front View: *C-CaSBr*

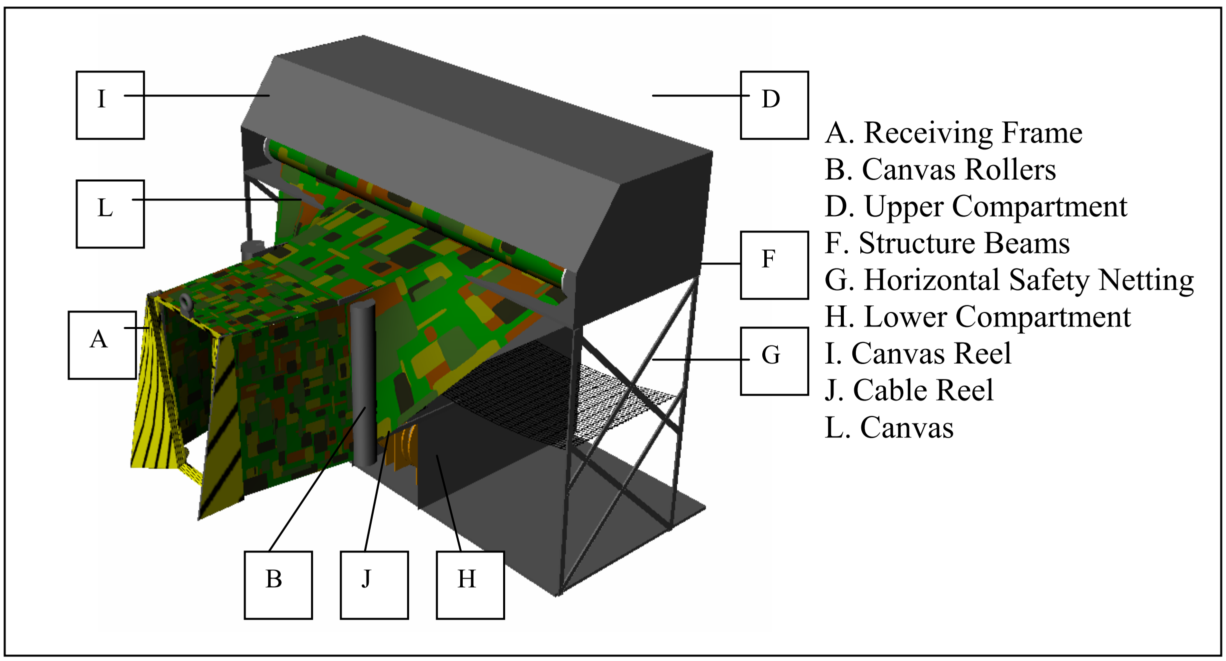


Figure A.C.4: Orthogonal View of *C-CaSBr*, Extended, Rendered

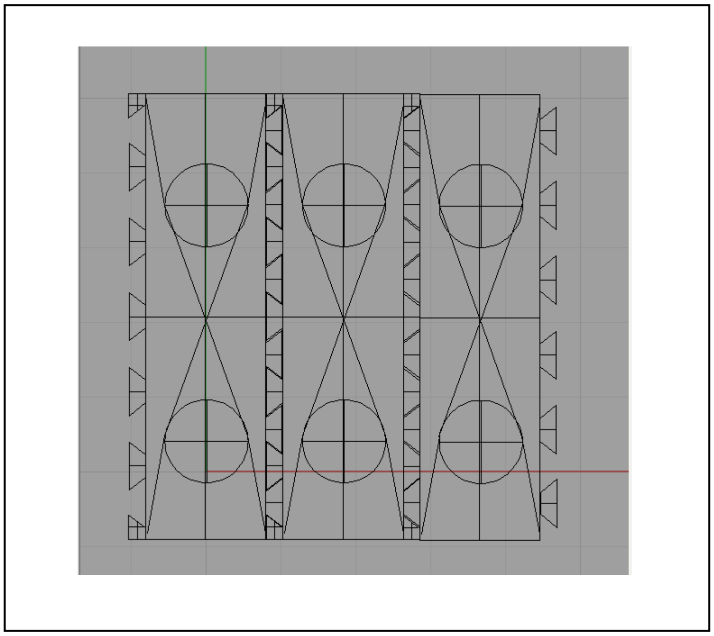


Figure A.C.5: Underside of Composite Flooring

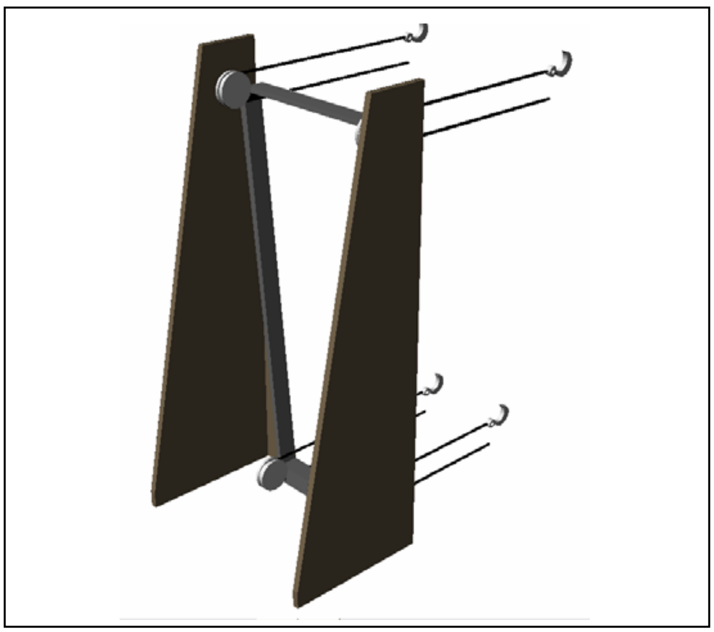
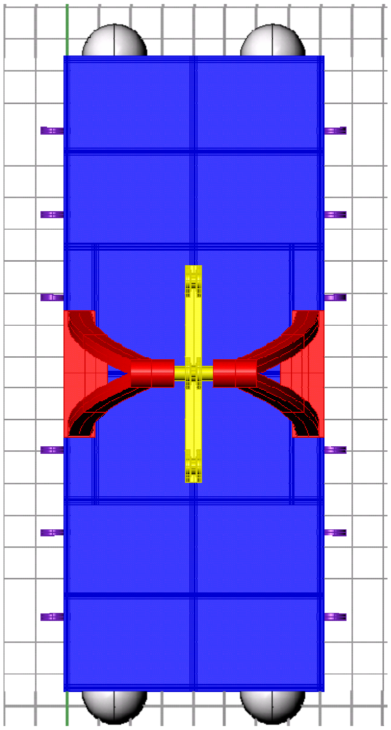
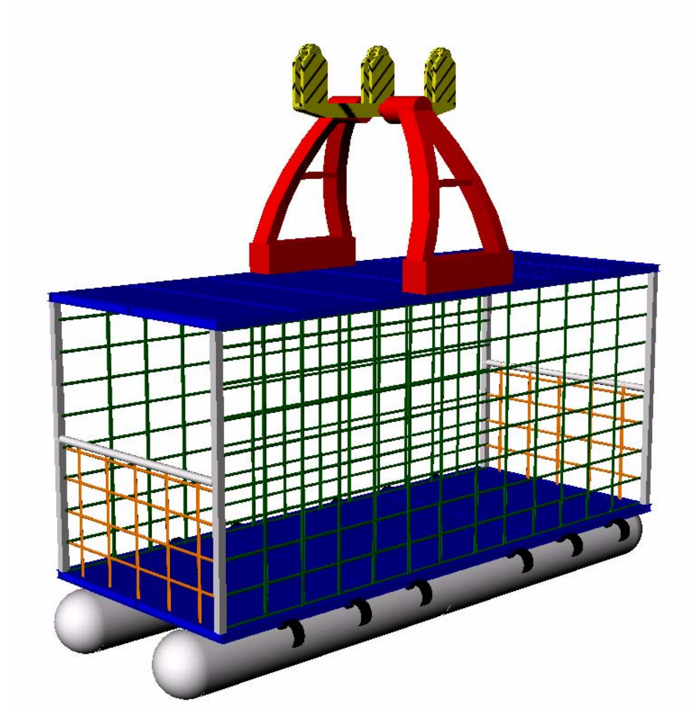


Figure A.C.6: Evolution of Design; Pulley/ Frame System

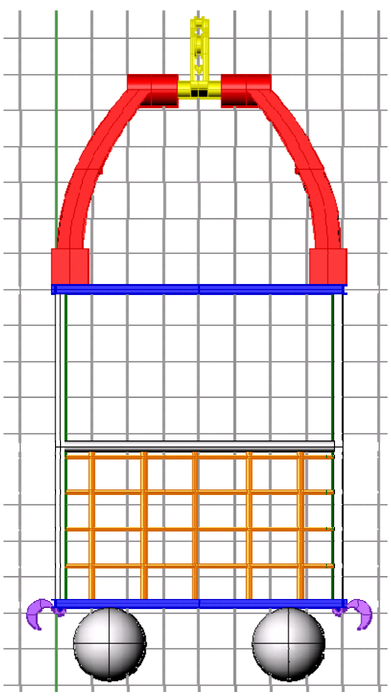
Appendix D: *ASPALT* Views



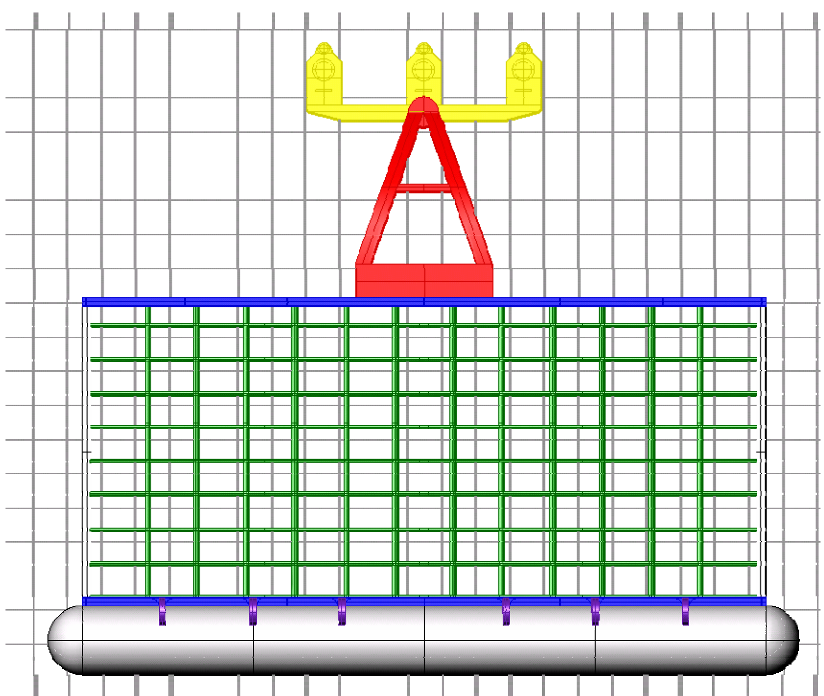
A.D.1: Top View



A.D.2: Isometric View



A.D.3: Front View



A.D.4: Right Side View

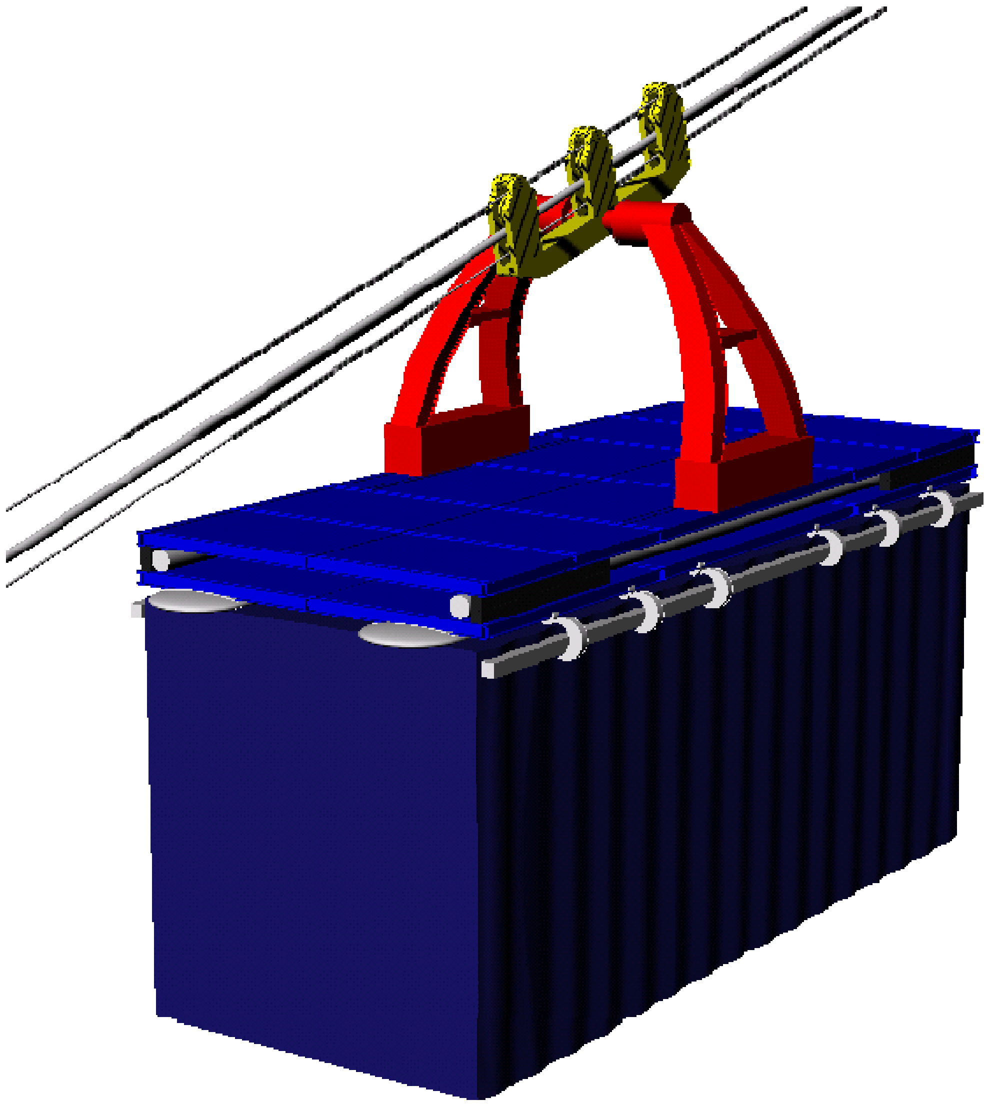


Figure A.D.5: *ASPALT* with TEU Container

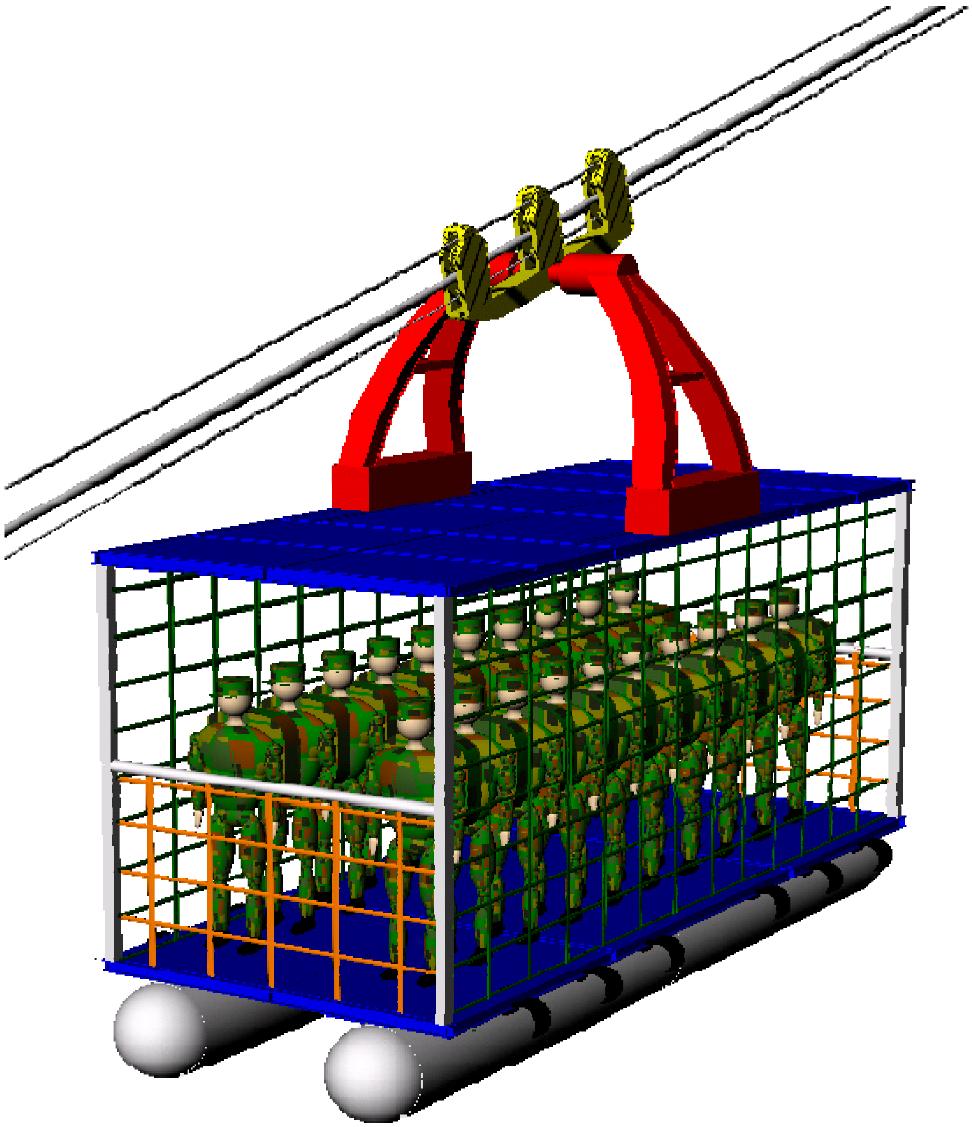


Figure A.D.6: *ASPALT* with personnel

Appendix E: Material Properties

Material Properties			
Material	Density (g/cc)	Young's Modulus (psi)	Poisson's Ratio
Stainless Steel (304)	8.03	30458400	0.3
Ti Alloy	4.506	14504000	0.33
Al Alloy	2.7	11023040	0.32
Carbon Fiber (High Density)	1.3	217560	0.28

Table A.E.1: Material Properties for *ASPALT*

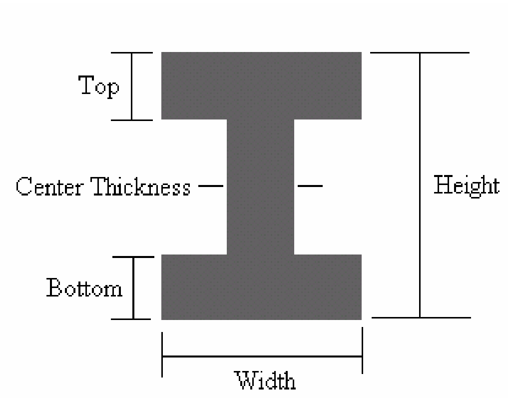


Figure A.E.1: I-beam cross section

I-Beam: 3" high, 2.509" wide, 0.349" thick center, 0.125" top and bottom			
Units:	ft^3	cm^3	m^3
Volume I-Beam (8ft):	0.088	2496.6	0.002
Volume I-Beam (20ft):	0.22	6241.5	0.006

I-Beam: 3" high, 2.509" wide, 0.349" thick center, 0.25" top and bottom			
Units:	ft^3	cm^3	m^3
Volume I-Beam (8ft):	0.118	3346.1	0.003
Volume I-Beam (20ft):	0.295	8365.3	0.008

I-Beam: 3" high, 2.509" wide, 0.349" thick center, 0.5" top and bottom			
Units:	ft^3	cm^3	m^3
Volume I-Beam (8ft):	0.178	5045.1	0.005
Volume I-Beam (20ft):	0.445	12613	0.013

I-Beam: 4" high, 2.796" wide, 0.326" thick center, 0.125" top and bottom			
Units:	ft^3	cm^3	m^3
Volume I-Beam (8ft):	0.141	3994.2	0.004
Volume I-Beam (20ft):	0.353	9985.6	0.01

I-Beam: 4" high, 2.796" wide, 0.326" thick center, 0.25" top and bottom			
Units:	ft^3	cm^3	m^3
Volume I-Beam (8ft):	0.141	3994.2	0.004
Volume I-Beam (20ft):	0.353	9985.6	0.01

I-Beam: 4" high, 2.796" wide, 0.326" thick center, 0.5" top and bottom			
Units:	ft^3	cm^3	m^3
Volume I-Beam (8ft):	0.21	5937.1	0.006
Volume I-Beam (20ft):	0.524	14838	0.015

Table A.E.2: Volumes of I-beams for *ASPALT* base and roof frames

Constructed with I-Beams: 3" high, 2.509" wide, 0.349" thick center, 0.125" top and bottom		
Material	Tare Weight (lb)	Total Weight (Tare+20*315lb)
Stainless Steel (304)	3009.788	9309.788
Ti Alloy	2022.470	8322.470
Al Alloy	1516.478	7816.478
Carbon Fiber (High Density)	1124.228	7424.228

Constructed with I-Beams: 3" high, 2.509" wide, 0.349" thick center, 0.25" top and bottom		
Material	Tare Weight (lb)	Total Weight (Tare+20*315lb)
Stainless Steel (304)	3491.048	9791.048
Ti Alloy	2292.520	8592.520
Al Alloy	1678.293	7978.293
Carbon Fiber (High Density)	1202.139	7502.139

Constructed with I-Beams: 3" high, 2.509" wide, 0.349" thick center, 0.5" top and bottom		
Material	Tare Weight (lb)	Total Weight (Tare+20*315lb)
Stainless Steel (304)	4453.566	10753.566
Ti Alloy	2832.638	9132.638
Al Alloy	2001.916	8301.916
Carbon Fiber (High Density)	1357.956	7657.956

Constructed with I-Beams: 4" high, 2.796" wide, 0.326" thick center, 0.125" top and bottom		
Material	Tare Weight (lb)	Total Weight (Tare+20*315lb)
Stainless Steel (304)	3307.890	9607.890
Ti Alloy	2189.747	8489.747
Al Alloy	1616.711	7916.711
Carbon Fiber (High Density)	1172.491	7472.491

Constructed with I-Beams: 4" high, 2.796" wide, 0.326" thick center, 0.25" top and bottom		
Material	Tare Weight (lb)	Total Weight (Tare+20*315lb)
Stainless Steel (304)	3858.235	10158.235
Ti Alloy	2498.546	8798.546
Al Alloy	1801.745	8101.745
Carbon Fiber (High Density)	1261.580	7561.580

Constructed with I-Beams: 4" high, 2.796" wide, 0.326" thick center, 0.5" top and bottom		
Material	Tare Weight (lb)	Total Weight (Tare+20*315lb)
Stainless Steel (304)	4958.836	11258.836
Ti Alloy	3115.883	9415.883
Al Alloy	2171.655	8471.655
Carbon Fiber (High Density)	1439.683	7739.683

Table A.E.3: Weights of *ASPALT* constructed out of various I-beam thicknesses

Appendix F: *PTS* Views

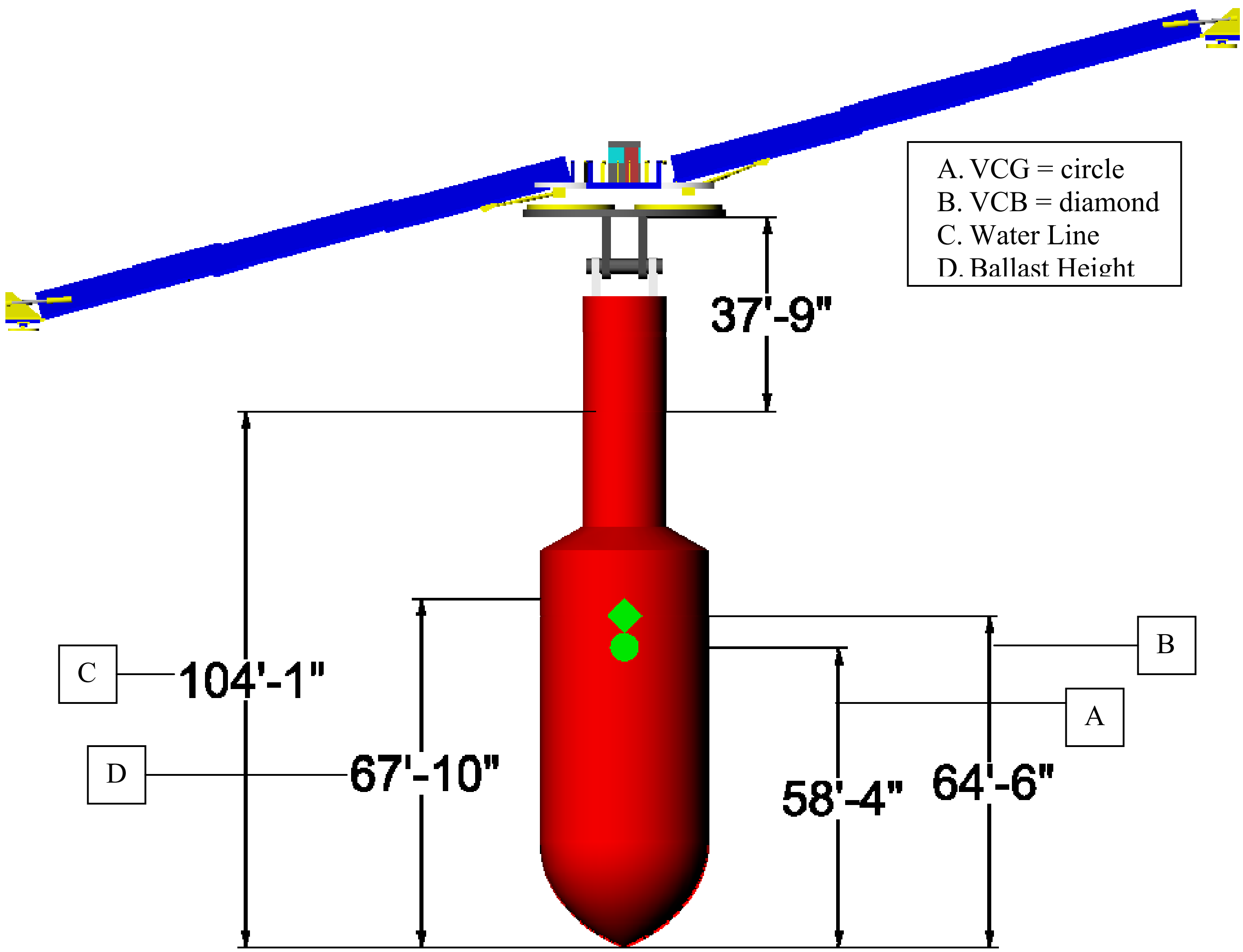


Figure A.F.1: Waterline View *PTS*

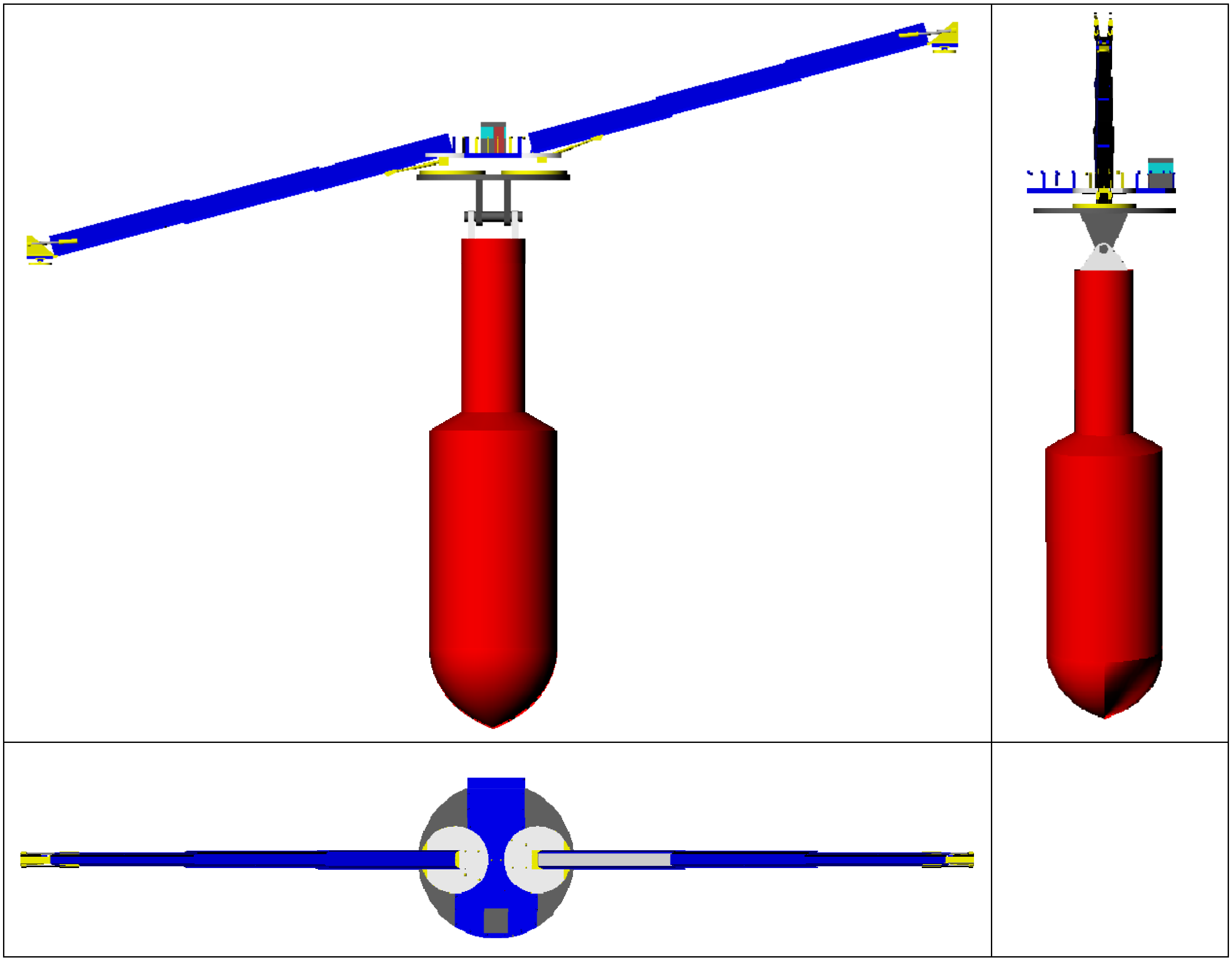


Figure A.F.2: Assorted View *PTS*

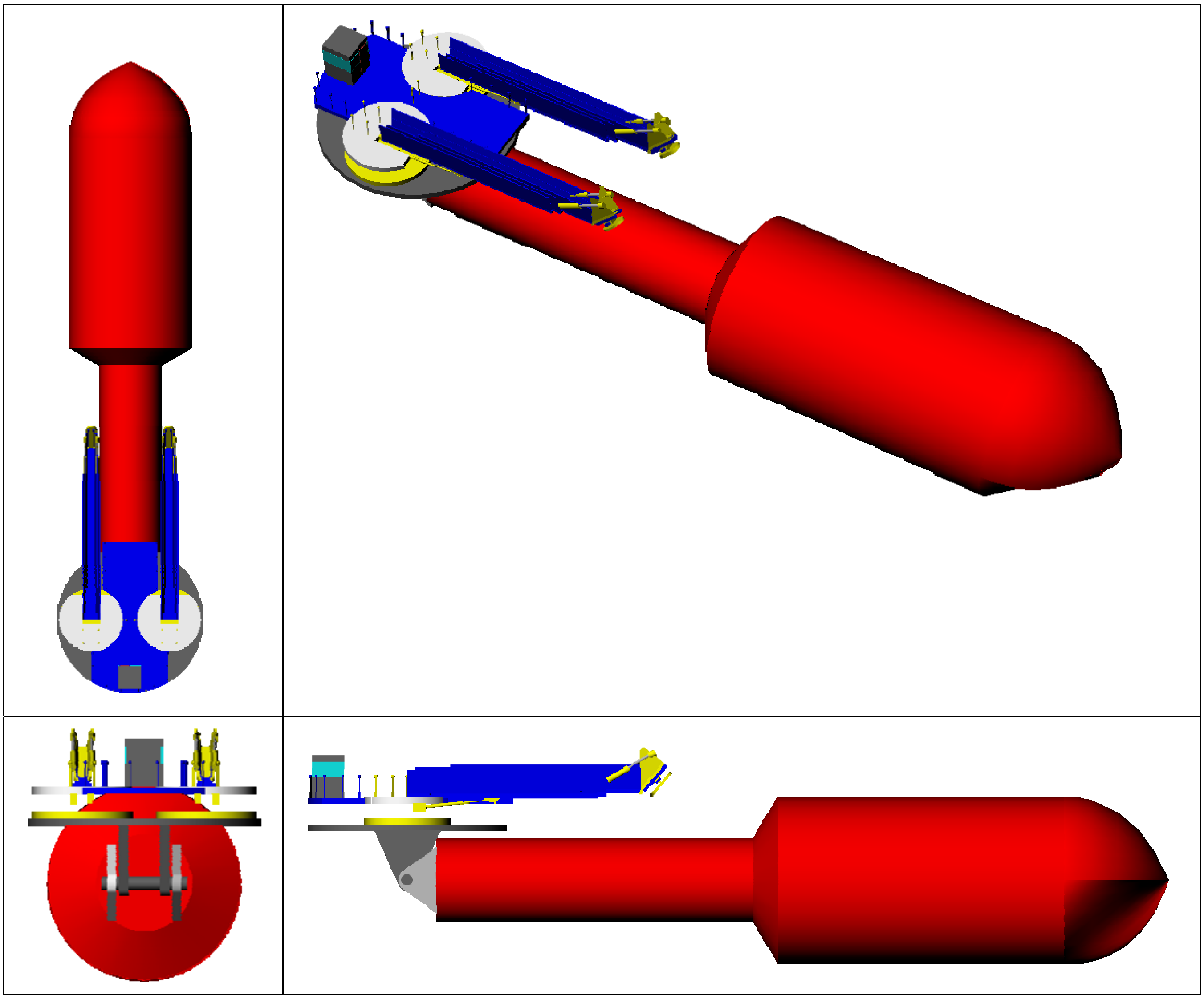


Figure A.F.3: Assorted View *PTS* Stored

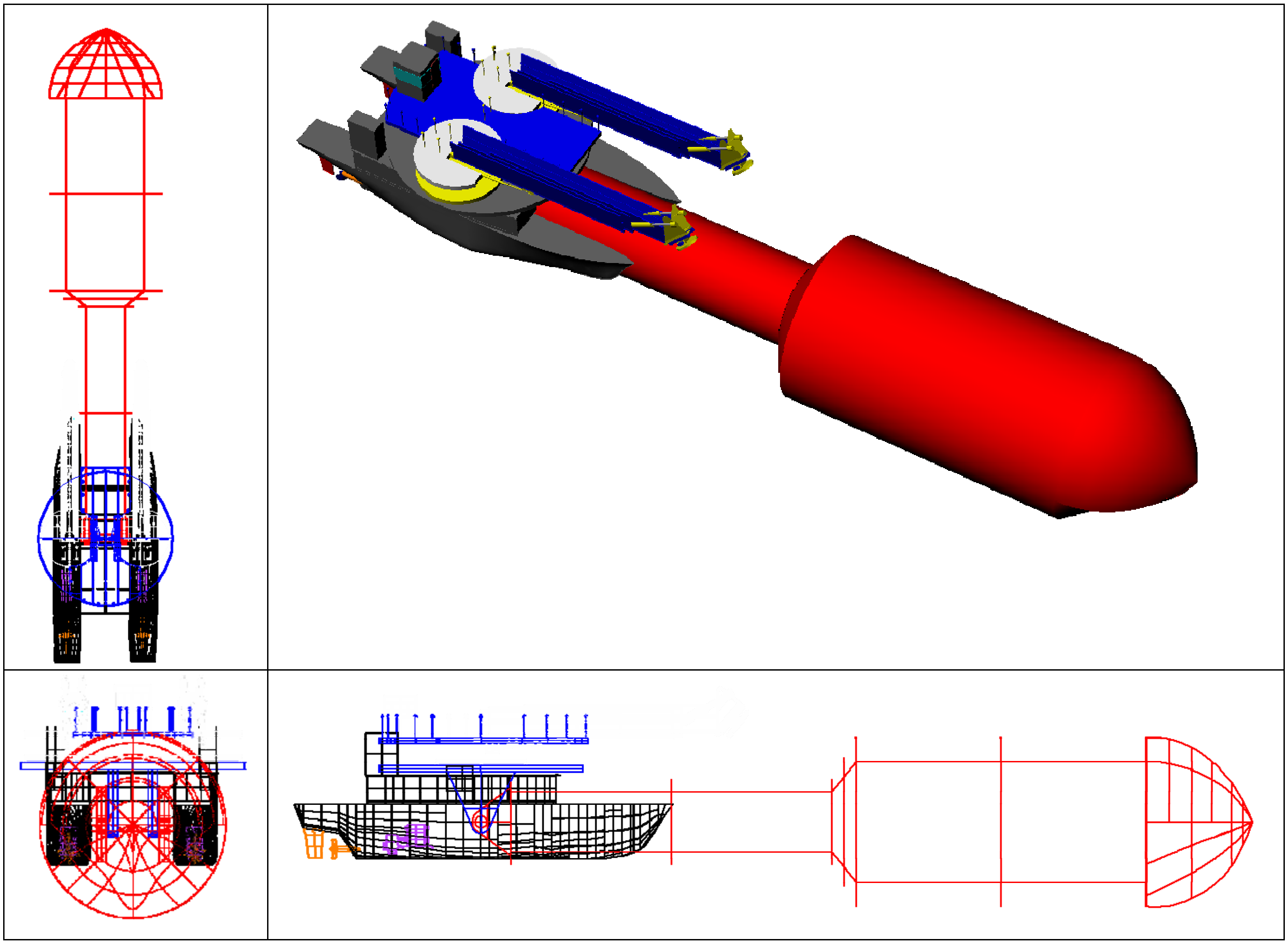


Figure A.F.4: Assorted View *PTS* Catamaran

Appendix G: *C-CaSBr* Calculations

Only basic calculations were carried out while evaluating the *C-CaSBr* concept do to time constraints as well as lack of adequate mathematical programming abilities. The calculations which were deemed vital to the development of the *C-CaSBr* were: weight, the diameter of reels, general forces at each end and throughput rate.

To find the weight of a 200 foot system, the design was broken down into three main components. The first component was the Plasma® rope. The particular rope chosen for this design was a 12x12 strand 1-5/8 inch diameter rope weighing 65.7 lbs per 100 feet. For the total weight of all four cables measuring 200 feet in length

$$200\,ft \times \frac{65.7lbs}{100\,ft} \times 4cables = 525.6lbs \qquad \text{(E A.G.1)}$$

The flooring is based off of standard flooring used for stadium events. According to Event Deck, a module with a thickness of ¾" weighs 0.81 lbs/ ft^2. Therefore, flooring with a width of 2.5 feet, and a length of 200 feet would weigh

$$0.81\frac{lbs}{ft} \times 2.5\,ft \times 200\,ft = 405lbs \qquad \text{(E A.G.2)}$$

Canvas, like all fabric, is usually described using ounces as the rating factor. The particular canvas chosen for this design was an 18 ounce (1.125lbs) fabric. This means that for one yard of the canvas, 62 inches wide, weighs 18 ounces, which reduces to 0.0726 lbs/ft^2. Since holes were cut into every square foot of fabric, further calculations were required before the final weight could be found. The area of the two holes removed from each square foot of fabric was found to be

$$2\pi \times \left(\frac{1.25}{12}\,ft\right)^2 = 0.0684\,ft^2 \qquad \text{(E A.G.3)}$$

By multiplying this by the weight per square foot previously found, then subtracting the two, the final weight per square foot of canvas was found to be

$$0.0726\frac{lbs}{ft^2} - \frac{0.684\,ft^2}{1\,ft^2}\left(0.0726\frac{lbs}{ft^2}\right) = 0.0676\frac{lbs}{ft^2} \qquad \text{(E A.G.4)}$$

Therefore, for a section of 21.2 feet wide by 200 feet long canvas the total weight is

$$0.0676\frac{lbs}{ft^2} \times 21.2\,ft \times 200\,ft = 143.312lbs \qquad \text{(E A.G.5)}$$

Summing the weights for the four cables, flooring and canvas the total weight of materials in the system comes out to be 608.612 lbs.

For finding the outer diameters of spools when the materials are wound up, equation E 3.6 was used.

$$\sqrt{\frac{48Lt}{\pi}+C^2}=D \qquad \text{(E A.G.6)}$$

In equation E A.G.6, L is the length of material in inches, t is the thickness of material in inches, C is the inner (core) diameter in inches and D is the outer diameter in inches. For the cables, if each reel is made to allow three cables to be placed side by side around a core with a 3-inch core, the outer diameter will have to be 2.407 feet. The spool of canvas, with a core of 3.5 inches will have an outer diameter of 1.0706 feet. If the core of the flooring spool is 5.5 inches, the final outer diameter will measure 4.0157 feet.

To find the general forces on the system, assumptions and simplifications needed to be made. The first assumption is that the two lower, supporting cables are responsible for the only the weight of themselves, the flooring and the troops. The upper to cables support only their own weight and that of the canvas. Even though in the real world application of this system all wires are connected and share in supporting all the weight, these simplifications needed to be made so that the system could be solved on an elementary level. The second assumption is that each set of cables, the top and bottom, equally distributes the load between the two cables. This simplification allows only one cable on each level to be evaluated.

The connections points, the cable reels, can be modeled as pin joints at which no horizontal motion or moments can occur. Also, both the flooring and the canvas spools will be taken out of the equation to limit the number of reaction forces. This is done by assuming that each material will be laying on the respective set of cables and therefore not in tension. The last assumption is that each cable can be modeled using standard beam theory. Even though it would be ideal to model the system as a cable with both slack and tension, there is not enough known about the properties of the materials and the set up to solve such an equation.

The model for the lower cables can be diagramed as so

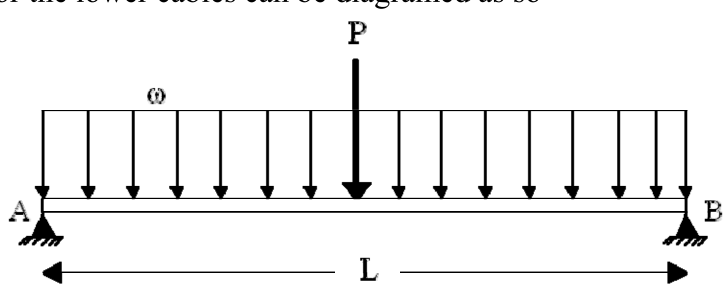


Figure A.G.1: Beam Diagram for Lower Cables

Where L is the entire length of the bridge, A is the location of the receiving ship, B is the

location of the delivery ship, ω is the weight of the cables and flooring, P is the weight of a single soldier. It can be seen in figure A.G.1 that the vertical reaction forces at positions A and B must be equal do to the symmetry in the system. By summing the forces in the vertical, or Y, direction, the reaction forces can be found.

$$\sum F_y = \omega \times L + P + 2R_F \qquad \text{(E A.G.7)}$$

with

$$\omega = 1.6695\frac{lbs}{ft}$$
$$L = 200\,ft \qquad \text{(E A.G.8)}$$
$$P = 315lbs$$

By assuming the system is in equilibrium, the sum of the forces in the Y direct can be set equal to zero.

$$\sum F_y = -1.6695\frac{lbs}{ft} \times 200\,ft - 315lbs + 2R_F = 0 \qquad \text{(E A.G.9)}$$

Solving for R_F, the reaction forces at either end of the beam:

$$R_F = 324.45lbs \qquad \text{(E A.G.10)}$$

The upper cables can be evaluated in a similar fashion using simple beam theory. The diagram as the system will be represented by

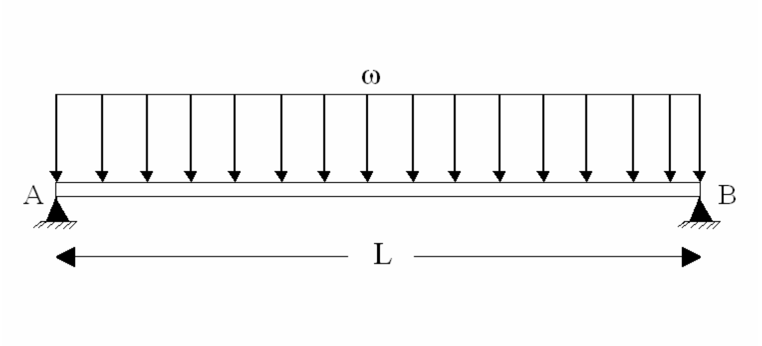


Figure A.G.2: Beam Diagram for Upper Cables

Where the variables are defined the same as in the previous case of the lower cables.

By summing the forces in the Y direction and setting it equal to zero, the vertical equilibrium equation looks like so:

$$\sum F_y = \omega \times L + 2R_F = 0 \qquad \text{(E A.G.11)}$$

with

$$\omega = 1.3736 \frac{lbs}{ft} \qquad \text{(E A.G.12)}$$

$$L = 200\,ft$$

$$\sum F_y = -1.3736 \frac{lbs}{ft} \times 200\,ft + 2R_F = 0 \qquad \text{(E A.G.13)}$$

Solving for R_F, the reaction forces at either end of the beam:

$$R_F = 137.36 lbs \qquad \text{(E A.G.14)}$$

To find the through put rate of this system, the average speed of a soldier walking was assumed to be 3.5 miles per hour. This is about the speed a person walks while exercising. A "brisk" pace as this is a safe estimate. It can be assumed that on average, a soldier will walk at a quicker pace, but by using a low estimate, it allows for mishaps during use such as uneven dispersion rates of men as well as tripping and falling.

It can be found that it will take the average soldier to cross a 200 foot span in approximately 38 seconds. However, this estimate is for a flat plane but the bridge will more than likely be at an incline. A 5 second safety buffer is added to the time, bringing the average time to 43 seconds. Assuming that one man is let across every 5 seconds, 5 men would cross every minute. Meaning that in an hour, roughly 300 men could make it from one ship to the other.

The maximum load on the lower cables at any one time would be 10 men according to the calculations above. Evaluating the forces at either end with this loading condition will be carried out as follows.

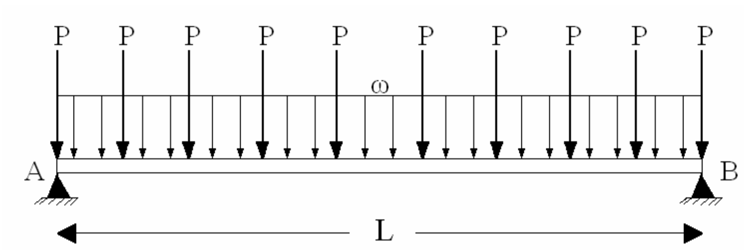


Figure A.G.3: Beam Diagram for Lower Cables with Max Loading Conditions

$$\sum F_y = \omega \times L + 10P + 2R_F = 0 \qquad \text{(E A.G.15)}$$

$$\sum F_y = -1.6695 \frac{lbs}{ft} \times 200\,ft + 10(-315 lbs) + 2R_F = 0 \qquad \text{(E A.G.16)}$$

$$R_F = 1741.95 lbs \qquad \text{(E A.G.17)}$$

Appendix H: *ASPALT* Calculations

Only basic assumptions and calculations were used as a means to convey the feasibility of the system. The most important calculations for the *ASPALT* are its projected weight and the amount of deflection the roof and base will experience. The structure of the roof and base of the *ASPALT* will consist of a relatively thin plate or canvas with a supporting frame underneath.

In order to find the projected weight of the system materials were chosen based on strength, density, sea worthiness, and longevity at sea. The process started by choosing four different materials to fabricate the roof and base which are: stainless steel, aluminum alloy, titanium alloy, and high-density carbon fiber composite. First the weights of plates covering the base of varying thicknesses were calculated. This was done by looking up each of the materials densities (Marcus Materials Co. ®) and using a known volume to estimate the weight:

0.125" Thick Plate (20' X 8')			
Material	Density (g/cc)	Weight (kg)	Weight (lb)
Stainless Steel (304)	8.030	378.976	835.490
Ti	4.506	212.661	468.830
Al	2.700	127.427	280.930
Carbon Fiber (High Density)	1.300	61.354	135.260
0.25" Thick Plate (20' X 8')			
Material	Density (g/cc)	Weight (kg)	Weight (lb)
Stainless Steel (304)	8.030	757.935	1671.000
Ti	4.506	425.312	937.653
Al	2.700	254.848	561.843
Carbon Fiber (High Density)	1.300	122.704	270.517
0.48" Thick Plate (20' X 8')			
Material	Density (g/cc)	Weight (kg)	Weight (lb)
Stainless Steel (304)	8.030	1455.300	3208.300
Ti	4.506	816.613	1800.320
Al	2.700	489.316	1078.760
Carbon Fiber (High Density)	1.300	235.596	519.401

Table A.H.1: Plate Weights

These plates are merely platforms for occupants to stand on. Material could also be removed from the plate to decrease its weight while keeping its rigidity. A plate of these sizes alone could not simply support the occupants inside the *ASPALT*; therefore it requires an underlying frame. This frame will consist of I-beams in various sizes in the configuration shown in figure 4.2.5, and the weights of these four materials were calculated in the same manner as the plates, with the only difference being volumes. The size of each I-beam was derived from the McMaster Carr ® inventory and used as a standard in which these calculations are based.

I-Beam: 3" high, 2.509" wide, 0.349" thick center, 0.125" top and bottom				
Material	Weight (kg, 20ft)	Weight (kg, 8ft)	Weight (lb, 20ft)	Weight (lb, 8ft)
Stainless Steel (304)	50.119	20.048	110.490	44.198
Ti alloy	28.124	11.250	62.003	24.801
Al alloy	16.852	6.741	37.152	14.861
Carbon Fiber (High Density)	8.114	3.246	17.888	7.155

I-Beam: 3" high, 2.509" wide, 0.349" thick center, 0.25" top and bottom				
Material	Weight (kg, 20ft)	Weight (kg, 8ft)	Weight (lb, 20ft)	Weight (lb, 8ft)
Stainless Steel (304)	67.173	26.869	148.090	59.236
Ti alloy	37.694	15.078	83.101	33.240
Al alloy	22.586	9.034	49.794	19.918
Carbon Fiber (High Density)	10.875	4.350	23.975	9.590

I-Beam: 3" high, 2.509" wide, 0.349" thick center, 0.5" top and bottom				
Material	Weight (kg, 20ft)	Weight (kg, 8ft)	Weight (lb, 20ft)	Weight (lb, 8ft)
Stainless Steel (304)	101.282	40.512	223.290	89.314
Ti alloy	56.834	22.733	125.300	50.118
Al alloy	34.055	13.622	75.077	30.031
Carbon Fiber (High Density)	16.397	6.559	36.148	14.459

I-Beam: 4" high, 2.796" wide, 0.326" thick center, 0.125" top and bottom				
Material	Weight (kg, 20ft)	Weight (kg, 8ft)	Weight (lb, 20ft)	Weight (lb, 8ft)
Stainless Steel (304)	60.684	24.273	133.780	53.513
Ti alloy	34.052	13.621	75.072	30.029
Al alloy	20.404	8.162	44.983	17.993
Carbon Fiber (High Density)	9.824	3.930	21.659	8.663

I-Beam: 4" high, 2.796" wide, 0.326" thick center, 0.25" top and bottom				
Material	Weight (kg, 20ft)	Weight (kg, 8ft)	Weight (lb, 20ft)	Weight (lb, 8ft)
Stainless Steel (304)	80.184	32.073	176.780	70.710
Ti alloy	44.995	17.998	99.197	39.678
Al alloy	26.961	10.784	59.439	23.775
Carbon Fiber (High Density)	12.981	5.192	28.619	11.447

I-Beam: 4" high, 2.796" wide, 0.326" thick center, 0.5" top and bottom				
Material	Weight (kg, 20ft)	Weight (kg, 8ft)	Weight (lb, 20ft)	Weight (lb, 8ft)
Stainless Steel (304)	119.149	47.674	262.760	105.105
Ti alloy	66.860	26.752	147.401	58.979
Al alloy	40.062	16.030	88.322	35.340
Carbon Fiber (High Density)	19.289	7.718	42.525	17.016

Table A.H.2: I-Beam Weights

The next sets of calculations are related to deflection in both the roof and base of the *ASPALT*. These series of calculations are based on the assumption that the roof and base is a long simply supported plate, bending cylindrically, when applied with a distributed load represented by:

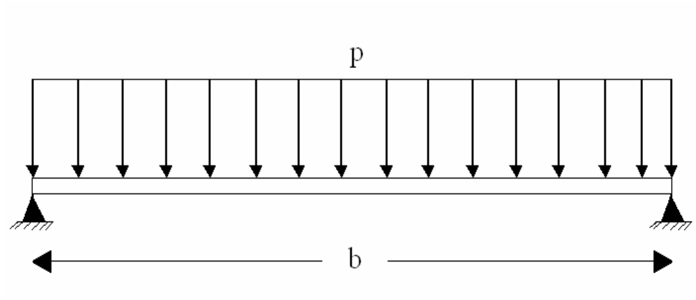


Figure A.H.1: Plate Deflection

These assumptions are a rough estimate of the deflections these plates will experience. The maximum deflection was calculated using this equation:

$$w_{\max} = \frac{5pb^4(1-v^2)}{32Et^3} \qquad \text{(E A.H.1)}$$

The term "*p*" stands for the applied pressure and is assumed to be uniformly distributed, the "*b*" term stands for the width of the plate which is 96 inches, "*v*" is Poisson's ratio, "*E*" is the elastic modulus, and "*t*" is the thickness of the plate (Hughes 333). In calculating the pressure applied to the base, the weight of each personnel that most likely will occupy the *ASPALT* was determined through the STO-PAC report to be 315 lbs including the equipment each carries (Anderson et al. 52). In addition to the weight of 20 personnel, the weight of the entire base must also be added including the inflatable tubes and tubes represented in table A.H.3:

I-Beam: 3" high, 2.509" wide, 0.349" thick center, 0.125" top and bottom			
Material	Weight of base (lb)	Pressure (psi)	Deflection of base (in)
Stainless Steel (304)	7823.750	2.717	0.035
Ti	7234.044	2.512	0.067
Al	6931.830	2.407	0.085
Carbon Fiber (High Density)	6697.545	2.326	4.284

I-Beam: 3" high, 2.509" wide, 0.349" thick center, 0.25" top and bottom			
Material	Weight of base (lb)	Pressure (psi)	Deflection of base (in)
Stainless Steel (304)	7996.705	2.777	0.036
Ti	7331.094	2.546	0.068
Al	6989.982	2.427	0.086
Carbon Fiber (High Density)	6725.545	2.335	4.302

I-Beam: 3" high, 2.509" wide, 0.349" thick center, 0.5" top and bottom			
Material	Weight of base (lb)	Pressure (psi)	Deflection of base (in)
Stainless Steel (304)	8342.616	2.897	0.038
Ti	7525.202	2.613	0.070
Al	7106.284	2.467	0.087
Carbon Fiber (High Density)	6781.541	2.355	4.338

I-Beams: 4" high, 2.796" wide, 0.326" thick center, 0.125" top and bottom			
Material	Weight of base (lb)	Pressure (psi)	Deflection of base (in)
Stainless Steel (304)	7930.882	2.754	0.016
Ti	7294.160	2.533	0.029
Al	6967.852	2.419	0.037
Carbon Fiber (High Density)	6714.890	2.332	1.867

I-Beams: 4" high, 2.796" wide, 0.326" thick center, 0.25" top and bottom			
Material	Weight of base (lb)	Pressure (psi)	Deflection of base (in)
Stainless Steel (304)	8128.669	2.822	0.016
Ti	7405.135	2.571	0.030
Al	7034.348	2.442	0.038
Carbon Fiber (High Density)	6746.907	2.343	1.876

I-Beams: 4" high, 2.796" wide, 0.326" thick center, 0.5" top and bottom			
Material	Weight of base (lb)	Pressure (psi)	Deflection of base (in)
Stainless Steel (304)	8524.190	2.960	0.017
Ti	7626.950	2.648	0.031
Al	7167.260	2.489	0.038
Carbon Fiber (High Density)	6810.900	2.365	1.894

Table A.H.3: Deflection estimation for base

This load estimation was given a safety factor of 8 as a precaution since personnel are the primary users. The results for the base indicate only minor deflection with a safety factor of 8, but realistically the deflection will be slightly higher. According to these calculations high density carbon fiber deflects the most. These calculations imply the carbon fiber plating is only 0.125 inches thick, but that thickness can change in order for the carbon fiber to have properties similar to any of the three metals and minimize deflection. The same assumptions used to calculate the deflection of the base will apply to the roof portion of the *ASPALT*.

The roof portion of the *ASPALT* is much like the base except that the weight of the posts and mesh now come into play in addition to the load carried by the bottom. The calculations were made using equation A.H.1.

I-Beam: 3" high, 2.509" wide, 0.349" thick center, 0.125" top and bottom			
Material	Weight of roof and base (lb)	Pressure (psi)	Deflection of roof (in)
Stainless Steel (304)	8809.788	3.059	0.040
Ti	7822.470	2.716	0.073
Al	7316.478	2.540	0.090
Carbon Fiber (High Density)	6924.228	2.404	4.429

I-Beam: 3" high, 2.509" wide, 0.349" thick center, 0.25" top and bottom			
Material	Weight of roof and base (lb)	Pressure (psi)	Deflection of roof (in)
Stainless Steel (304)	9291.048	3.226	0.042
Ti	8092.520	2.810	0.075
Al	7478.293	2.597	0.092
Carbon Fiber (High Density)	7002.139	2.431	4.479

I-Beam: 3" high, 2.509" wide, 0.349" thick center, 0.5" top and bottom			
Material	Weight of roof and base (lb)	Pressure (psi)	Deflection of roof (in)
Stainless Steel (304)	10253.566	3.560	0.046
Ti	8632.638	2.997	0.080
Al	7801.916	2.709	0.096
Carbon Fiber (High Density)	7157.956	2.485	4.578

I-Beams: 4" high, 2.796" wide, 0.326" thick center, 0.125" top and bottom			
Material	Weight of roof and base (lb)	Pressure (psi)	Deflection of roof (in)
Stainless Steel (304)	9107.890	3.162	0.018
Ti	7989.747	2.774	0.032
Al	7416.711	2.575	0.040
Carbon Fiber (High Density)	6972.491	2.421	1.939

I-Beams: 4" high, 2.796" wide, 0.326" thick center, 0.25" top and bottom			
Material	Weight of roof and base (lb)	Pressure (psi)	Deflection of roof (in)
Stainless Steel (304)	9658.235	3.354	0.019
Ti	8298.546	2.881	0.033
Al	7601.745	2.639	0.041
Carbon Fiber (High Density)	7061.580	2.452	1.964

I-Beams: 4" high, 2.796" wide, 0.326" thick center, 0.5" top and bottom			
Material	Weight of roof and base (lb)	Pressure (psi)	Deflection of roof (in)
Stainless Steel (304)	10758.836	3.736	0.021
Ti	8915.883	3.096	0.036
Al	7971.655	2.768	0.043
Carbon Fiber (High Density)	7239.683	2.514	2.013

Table A.H.4: Deflection estimation for top

Again these deflections are small with the exception of high density carbon fiber and should not be taken literally. The overall data roughly indicates how stable the design is with 8 times the projected capacity. More accurate data can be achieved utilizing a finite element analysis program, but that is beyond the scope of these feasibility calculations.

The throughput rate was calculated based on the time it takes for the *ASPALT* to span the distance between two vessels. The distance between two vessels can be at 140 feet or 160 feet depending on sea state. As a result two sets of calculations were conducted with an estimated velocity of an UNREP rig at 15 feet/second (Tschiegg).

Throughput Rate		
Distance	140 feet	160 feet
Velocity	15 feet/second	
Cycle Time	78.67 seconds	81.33 seconds
Number of personnel	20	
Rate	457 men/hour	442 men/hour

Table A.H.5: Throughput Rate

For a distance of 140 feet, it would take the *ASPALT* 18.67 seconds to reach the other vessel. Sixty seconds was estimated and added to account for the loading and unloading of personnel; therefore, total time of travel is estimated at 78.67 seconds for a distance of 140 feet. There will be a dwell period when the *ASPALT* is sent back to the delivery vessel empty, and that was accounted for by dividing the rate by two. The same method was repeated for a distance of 160 feet.

Appendix I: *PTS* Calculations

The bridge will be capable of moving through a range of 90º but the greatest moments will occur when the bridge is horizontal and fully extended to 100 feet. To find the shear and moment diagrams the bridges were modeled with a beam that is pin supported at either side. The summation of forces was taken, with F_C representing the weight of a marine and the distributed weight of the ladder denoted as ω. For the calculations the distributed load ω was ignored because an accurate weight could not be determined for the bridges. All calculations will be considered additional stress on the system created by the presence of the personnel. The calculations can be subsidized in the future by finding better estimates for weights of the bridges.

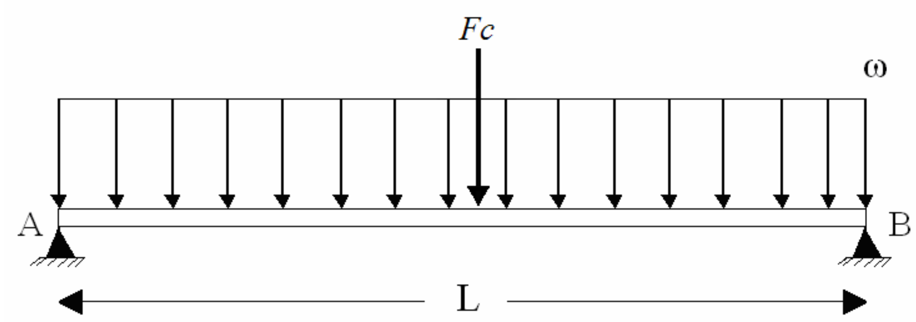


Figure A.I.1: Beam Diagram for Bridge

$$\sum F_y = 0 \Rightarrow F_A + F_B - F_C + \omega L \qquad \text{(E A.I.1)}$$
$$F_C = 315lbs + \omega L$$
$$F_A = F_B = 157.5lbs + \omega L/2$$

From here the shear and moment diagrams could be drawn, and a maximum internal moment can be determined.

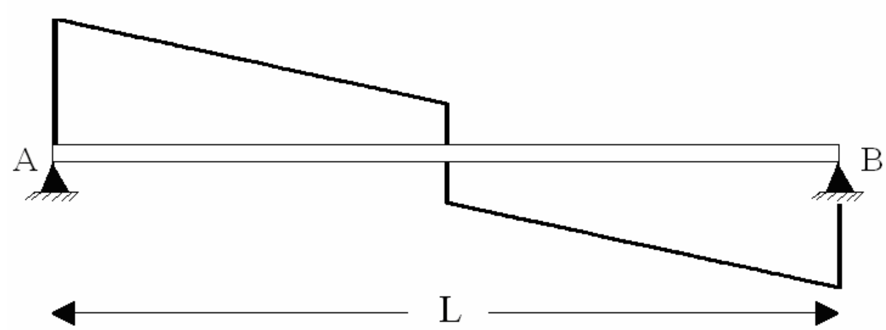


Figure A.I.2: Shear Diagram for Bridge

(E A.I.2)

$$V_A = V_B = 157.5lbs + \omega L / 2$$

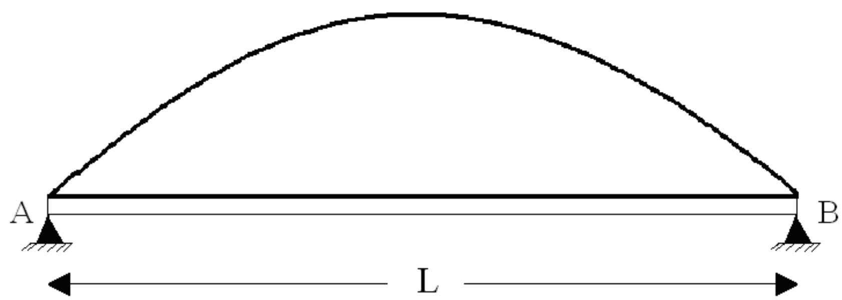


Figure A.I.3: Moment Diagram for Bridge

The slope of the moment diagram is equal to the shear at the equivalent point,

$$dM / dx = V \tag{E A.I.3}$$

To determine the maximum internal moment the beam is cut where the moment diagram peeks and a summation of moment forces is calculated using the remaining section.

$$\sum M = 0 \Rightarrow F_A(50) - (\omega L/2)(25) + M_{Max} = 0 \tag{E A.I.4}$$

$$M_{Max} = (157.5)(50) - (\omega L/2)(25)$$

$$M_{Max} = 7875lbs.ft - (\omega L/2)(25)$$

The bridges are subject to a maximum internal moment of 7875 lbs.feet and a shearing force of 157.5 lbs as a result of a single marine.

If the bridges become disconnected during the transfer process they are designed to maintain position, with marines aboard. The most stressful arrangement for the system would be produced by having the bridge in the horizontal position and a marine at the very end of the extended bridge. To model this, a cantilever beam, fixed at one end, with the weight of a marine and gear, F_C at the other.

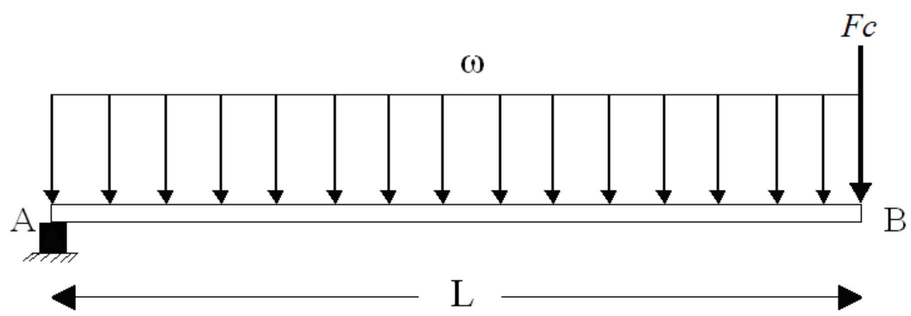


Figure A.I.4: Cantilever Beam Model

The summation of forces can be done the same as before,

$$\sum F_y = 0 \Rightarrow F_A - F_C - \omega L \qquad \text{(E A.I.5)}$$

$$F_A = F_C + \omega L = 157.5lbs + \omega L$$

For a cantilever beam the maximum moment will occur at the fixed end,

$$M_A = F_C(100) + (\omega L)(50) = 31500lbs + (\omega L)(50) \qquad \text{(E A.I.6)}$$

In the case of detachment and a marine is located at the very end of the bridge he will cause a moment of 31500 lbs at the base of the structure.

Based on the measurements found in the Vessel Characteristics for Shiploading, an LMSR deck is about 70 feet off the ocean surface at light ship conditions. The LCU is roughly 6 feet from the ocean surface and the *PTS* deck is 36 feet from the ocean surface. With 100 feet long bridges the angle from the LCU to the PTS is,

$$Sin\theta = \frac{o}{h} \qquad \text{(E A.I.7)}$$

$$\theta = Sin^{-1}\frac{o}{h} = Sin^{-1}\frac{30}{100} = 17.5^o$$

The angle between the PTS to the LMSR will be greater than that between the *PTS* and the LCU because the difference in relative heights increases by 4 feet.

$$\theta = Sin^{-1}\frac{o}{h} = Sin^{-1}\frac{34}{100} = 20^o$$

These angles are acceptable, allowing the system to comfortable fall within the 90º range and leaving enough room for roll compensation.

The TPF or ton per foot of the *PTS* helps determine how sensitive the system is to changes in weight such as load and unload of marines or fuel consumption. The TPF is determined by using the diameter of the *PTS* at the water surface, which is easily variable but for this design a 16.5 feet. diameter was used and the density of the salt water was assumed to be 64lb/ft^3. The ton per foot is equal to the weight *W,* of the displaced volume *V* of water for one foot of vertical height,

$$TPF = W / ft. \quad \text{(E A.I.8)}$$

$$V = \pi \frac{D^2}{4} h = \pi \frac{16.5^2}{4} 1 = 214 ft^3$$

$$W = \rho V$$

$$W = 64 lb / ft^3 * 214 ft^3 = 13696 lbs$$

$$TPF = 6.848 tons / ft \quad \text{(E A.I.9)}$$